WORKSHOP PRACTICE

A PRACTICAL TEXT BOOK

REVISED BY

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WORKSHOP PRACTICE

CHAPTER I

MEASUREMENTS AND MEASURING MACHINES

THE successful output of finished articles from modern engineering workshops depends so much on accuracy and interchangeability, that the use of standard gauges is absolutely imperative. Before, however, standard gauges can be made, it is necessary to have a standard of measurement.

Standards of Measurement.—The unit of measurement most frequently used in the United Kingdom is the Standard Imperial Yard. This unit of measurement is the distance between two very fine lines on polished gold studs, inserted in a bronze rod, called Bronze No. 1, and kept in the Standards Office of the Board of Trade. The standard yard was legalised by the British Government in 1855, and a number of copies were made and distributed to various governments. Of those made, Nos. 19 and 28 were exact standards, and were retained as exact standards.

Divisions of the Yard and Foot.—The division of the standard yard is in three equal parts, each part being termed a foot; a subdivision of the foot is made which gives twelve equal parts, each being called an inch. In mechanical engineering and similar practice, the inch as a standard is used more frequently than the yard or foot, because a greater amount of work comes inside the limits of 12 in. than outside.

Divisions of the Inch.—The inch is divided for purposes of measurement into any convenient number of divisions. These divisions or fractions may be represented as either decimal or vulgar fractions of an inch. The former method is much to be preferred, and for fine measurements is generally used; in this case the denominator of the fraction is some power of 10, thus $\frac{1}{10}$, $\frac{1}{100}$, $\frac{1}{1000}$ are decimal fractions, and may be expressed as .1, .01, or .001.

When vulgar fractions are used, the binary method of making the denominator a multiple of 2 is generally employed, and by this means we get such fractions as $\frac{1}{4}$, $\frac{3}{8}$, $\frac{5}{16}$, and $\frac{3}{64}$. This limitation is necessary in order to restrict the number of possible dimensions, and because small tools such as drills and reamers are usually made in these sizes.

The determination of a standard unit of length is not by any means a simple operation, and the fact that a slight change in temperature alters the dimensions of most metals makes it impossible to guarantee that a measurement is absolutely correct. To show the importance of having a standard measure of length, Messrs Brown & Sharpe decided to make new standards to replace the ones that had been in their use since 1893. To carry this out they first prepared steel bars about 40 in. in length by $1\frac{1}{4}$ in. square, and after planing them they were allowed to rest for several months.

At the ends of the steel bars gold studs were inserted, the centres of which were 36 in. apart. A bar was placed

on a heavy bed and so arranged that a tool holder could be passed over the bar. The tool carrier consisted of a light framework holding the marking tool. One feature of the marking was that the point of the marking tool was moved and had an angle, so that if dropped it made an impression in the form of an ellipse. In graduations, ordinarily, the line when magnified is apt to present at its ends an impression less definite than in the centre, by reason of the form of the objective. The line made by the tool, as stated, is short, and that portion of the line is read which passes, apparently, through the straight line in the eye-glass of a microscope. In order to make these lines as definite as possible, the point was lapped to a bright surface. After being placed in position, the microscope, which could be attached to the front of the tool carrier, was set to compare with the graduation on the standard bar from which the new bar was to be prepared. After such a setting the readings were made by three persons, and by turning a lever the marking tool was dropped, making a very fine line, so fine, indeed, that when the authorities began the examination of the bar later on they declared that no line had been made upon the studs.

After making the first line, the carriage was moved along to compare with the other lines on the standard, and after the correction had been made by the use of the micrometer in the microscope, the marking tool was again dropped, giving a second line which was intended to mark the limit of one yard all over.

The same operation was repeated in the marking of the metre. The whole of this work was done with the utmost care, and while the theoretical portion appears very simple in detail, it required a great deal of time and patience before the last line could be made. The bar was next taken and compared with the Government standard. In

comparing with this standard, a process was gone through which was similar to that used in marking the bar. The bar, properly supported, was placed upon a box which rested upon rollers, and on this same box was placed the Government standard. The standard was placed in position under the microscope, and after being properly set to the standard, the bar to be measured was placed under the microscope, and the micrometer screw of the microscope and the variation were measured. Three comparisons were made by three different persons on each end before determining the reading of the microscope, and after such comparisons and many repetitions of them, the value of the standard was found to be 36.00061 in. for the yard, and 1.0000147 metres for the metre.

The Metric Standard

The Metric, or French method of measurement is based on the metre as a standard; this is equivalent to 39.37079 in. or 1.09361 of our standard yard. The metric standard is in current use on the Continent, but for economic reasons and the traditional feeling it is rarely used by engineering concerns within the United Kingdom.

The metre is subdivided into ten divisions, each being called a decimetre (dm.); these are also divided into ten equal divisions, each of which is termed a centimetre (cm.); the centimetres are divided into ten, each division being a millimetre (mm.).

Divisions of the Metre.

1 millimetre (mm.)	=	0·03937079 inch, or about $\frac{1}{25}$ inch
10 millimetres = 1 centimetre (cm.)	=	0·3937079 inch.
10 centimetres = 1 decimetre (dm.)	=	3·937079 inches.
10 decimetres = 1 metre (m.)	=	39·37079 inches.

The **Standard Steel Rule** for use in the tool-room and workshop is made in a very large variety of lengths, widths, and thicknesses, and can be obtained either of flexible or hardened steel. The square-cornered rule, Fig. 1, when made of hardened steel, is undoubtedly the

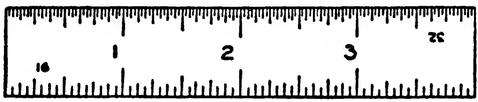


FIG. 1.—Steel Rule.

best rule for general purposes; the usual graduations when intended for measuring on the English standard are 64ths, 32nds, 16ths, and 8ths; but any number of graduations of the inch up to 100 can either be obtained, or specially made.

Rule Holders

A very convenient method of holding short rules is shown in Fig. 2. The holder shown is capable of taking five sizes of rules. The rules are held in a split chuck, adjusted by a knurled nut at the top of the barrel, and they can be set at various angles to suit the particular purpose desired.

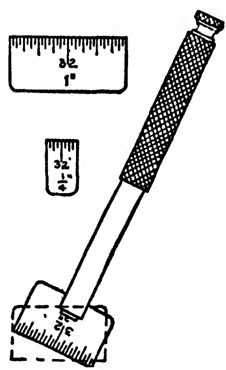


FIG. 2.—Rule Holder

This method of holding short rules will be found useful in cases where it is impossible to use the ordinary rule. Measuring keyways, dies, and small work is a simple matter with this tool.

An improvement on the standard steel rule is shown in Fig. 3. This improvement consists of a series of graduations at the end of the scale of hundredth as follows:—

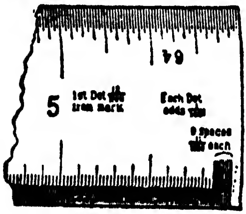


FIG. 3.—Improved Rule.

Nine spaces of eleven-thousandths of an inch each are marked and a diagonal line of eight dots, the one nearest the edge of the rule being twelve-thousandths of an inch from the last line, the second thirteen-thousandths, and so on, each dot one-thousandth of an inch farther from the line than the one preceding.

By the use of the eleven-thousandth graduations, measurements from one-tenth of an inch to any length on the scale can be made by thousandths of an inch, and by making use of the line of dots, dividers can be set by thousandths from one-hundredth of an inch to any part of the scale.

Method of Using

When required for measurements less than .100 in., use the long lines shown at the right for measurements that are multiples of 11, and the long lines and 1 – 100 in. space lines on the left for measurements that are the sums of multiples of 10 and 11.

The following measurements will illustrate the application of these rules:—

Required Measurement.	Method of Obtaining Measurement.		
	·011 In. Spaces.	·010 In. Spaces.	Dots.
In.			
·051	1	4	0
·052	2	3	0
·053	3	2	0
·054	4	1	0
·055	5	...	0
·056	5	...	1
·057	5	...	2
·058	5	...	3
·059	5	...	4
·060	–	6	0

When using the eleven-thousandth spaces and the dots, remember that the space between the long line and the first dot is the same as one .011 in. space plus .001 in., and reads .012 in. For measurements greater than .100 in., multiply the thousandths figure by 11 and subtract this result from the required measurement. Proceed as follows: Place one leg of the dividers in the line corresponding to the figure multiplied by 11, and the other leg in the hundredths line, corresponding to the hundredths found in the difference. For example: To measure .736 in., multiply 6 by .011 and subtract the result, .066, from the distance to be measured, .736 – .066 = .670. Then place one leg of the dividers in the line registering the sixth .011 in. space; this, as the first of these lines is o, will be the seventh line. Read back from this same o sixty-seven of the 1 – 100 in. spaces and the dividers will be open .736 in.

To take another example. Required 1.743 in.; since 1.743 – .033 = 1.710, place one leg of the dividers in the fourth long line and the other in the 171st 1 – 100 in. line.

Workshop Measurements

Owing to the development of large-scale production and the overriding need for interchangeable manufacture the old method by which the craftsman personally decided the fit for each portion of the machine or assembly, without considering the reaction upon service requirements, has largely disappeared, and to-day the general tendency is to state the limiting dimensions on both the shaft and in the bore, also on the length and width, on each drawing issued to the manufacturing section.

The change-over has been greatly facilitated by the steady introduction of mechanical and optical measuring instruments so that the rule and calipers are now used for what may be regarded as approximate measurements.

With modern machine tools maintained in first-class condition the semi-skilled person has, in a number of instances, no difficulty of working with limits of, say, plus or minus .0002 in. It should, however, be realised that the accuracy has been built into the machine, and the close dimensional limits obtained are largely independent of the personal factor. Gauge making, which is often a highly skilled job, may on occasions call for accuracy within .00005 in. or even less, and may require craftsmanship of the highest degree.

As an indication of the close degree of accuracy with which it is possible to work with first-class equipment, one may cite the standard gauge blocks as made by Johansson of Sweden. A full set of blocks consists of eighty-one pieces and will give with any combination an overall accuracy of .00004 in. at the standard temperature of 68° F. or 20° C.; this in spite of the fact that more than 80,000 different sizes can be built up from the standard series of block gauges.

Measuring Machines

In order to obtain the degree of accuracy required in modern interchangeable work, and for such purposes as checking standard and limit gauges, it is necessary that the up-to-date tool-room should be equipped with precision instruments of sufficient accuracy to eliminate any possibility of error in measurement.

When gauges are being manufactured, great accuracy is absolutely necessary, while standard and limit gauges

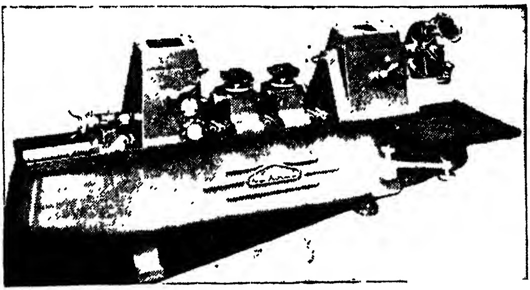


FIG. 4.—Measuring Machine.
(*By courtesy of Messrs Newall Engineering Co. Ltd., Peterborough.*)

require constant attention; this important work can only be carried out on a machine specially designed and made for that specific purpose.

Many reliable measuring machines are at present being manufactured. Fig. 4 illustrates a machine manufactured by the Newall Engineering Co., which has been specially constructed for this particular work, and at the same time it is suitable for the general precision work of the tool-room. It is an instrument very easy to use, and only a little patience and practice is required in order to attain proficiency in taking measurements of very great accuracy.

The combined features of the machine are such as to eliminate all possibility of personal error, and it maintains its accuracy and requires only a minimum of attention for adjustments.

Machines for English measurements are made to give readings to $\frac{1}{100000}$ of an inch (.00001 in.), the graduations on the measuring wheel being so designed and arranged that the indicated size can be read in decimals of an inch, the digits appearing in their proper rotation. For example, in a size or reading of .31254 in., as in Fig. 5, the first digit, 3, is the highest figure disclosed on the left-hand side of the scale carrying the vernier, the second and third digits, 1 and 2 respectively, appear as the highest main graduation, and the fourth digit, 5, as the highest subdivision, on the measuring wheel below, or in front of, the zero line on the vernier, and the fifth digit, 4, is that graduation on the vernier in line with any graduation on the measuring wheel.

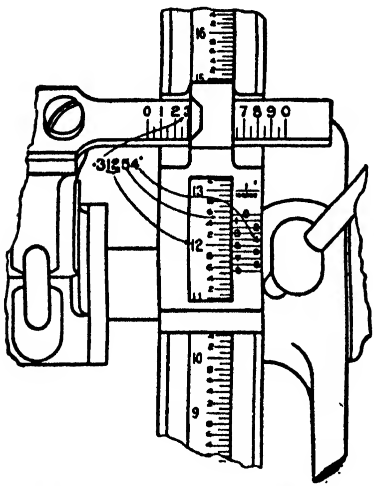


FIG. 5.—Readings on Newall Measuring Machine.

In machines for metric measurements the readings are given to $\frac{1}{10000}$ of a millimetre (.0001 mm.), the scale carrying the vernier is graduated in millimetres, and

the decimal parts of a millimetre appear in correct rotation on the graduated wheel and vernier as described for English readings. Fig. 6 shows an indicated size of 3.1254 mm.

As in machines for English measurements the pitch of the measuring screw is 20 per inch, it is necessary to add

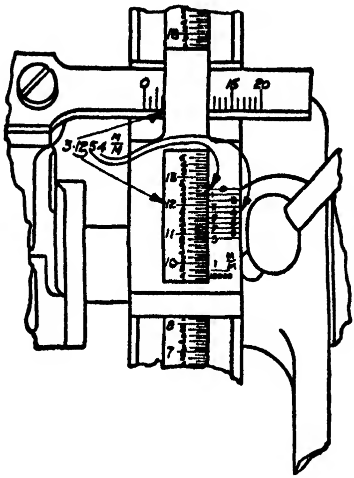


Fig. 6.—Metric Readings on Newall Machine.

.05000 in. to the amount of the indicated size in all cases where the vernier may have passed the subdivision between any two main divisions on the scale which carries the vernier. If in Fig. 5 the measuring wheel had been given one complete revolution outwards, the subdivision between digits 3 and 4 on the scale would appear, and the reading would then be .31254+.05000=.36254 in. The

pitch of the measuring screw in machines for metric measurement is 1 mm., and all readings of sizes are direct as indicated without necessity for any alterations.

The measuring screw bears a thread of buttress form cut specially deep to provide ample wearing surface, and has a range of 1 in., or 20 mm., according as it is intended for an English or metric machine respectively. The threaded portions of the screw and its nut are equal, of not less than three times the length of range stated above, and, wear being even, accuracy in pitch is maintained. Only a minimum amount of wear takes place on the effective portions of the thread, as the screw is supported on its plain cylindrical parts at front and rear in hardened steel bearings, which relieve the threaded part from weight and maintain the axis of screw and nut identical and invariable.

The measuring screws are guaranteed by the makers to be correct in pitch within $\frac{1}{10000}$ of an inch (.0001 in.), or $\frac{1}{400}$ (.0025) of a millimetre, for an English or metric thread respectively, for any length in their ranges given above. As a general rule, such fine screws are produced with an amount of error considerably smaller than stated, but, in order to provide for possible uncontrollable alterations, the wider margin is given.

Measuring

The piece to be measured is held or supported between the measuring points, and, by advancing the measuring screw until the bubble of the indicator attains its measuring position, the size of the piece is read off on the scale, wheel, and vernier. When advancing the measuring screw, the knurled nut on the end of the spindle is turned until sufficient pressure has been applied to start the bubble

from its resting position, then the fine adjustment arm is clamped and its screw brought into use to give slow movement to cause the bubble to travel to its measuring position, the critical point in all operations of setting or measuring. The subdivisions on the vial of the indicator are intended for the purpose of comparisons only, though their approximate value may be determined by observation and calculation if desired.

Whitworth Measuring Machine

The Whitworth measuring machine, shown in Fig. 7 for historical reasons, is arranged to measure by comparison with standard cylindrical or other gauges up to 6 in. diameter and 12 in. long, and to the ten-thousandth part of an inch, or with the vernier to the hundredth thousandth part of an inch over small ranges. The machine consists of an accurately finished bed, with feet cast on, carrying a screw and hand wheel for quickly setting the moving head approximately to a scale of inches marked on the face; a moving head and screw with divided hand wheel for adjusting the hardened contact piece of spindle in touch with the standard; and a right-hand fixed head with vernier, dividing wheel, screw, and spindle with hardened contact piece for measuring.

The function of the machine is comparative measurement from existing standards; thus given a 6-in. standard, another can be made any small amount under or over 6 in.

The measuring screw is that in the fast headstock with

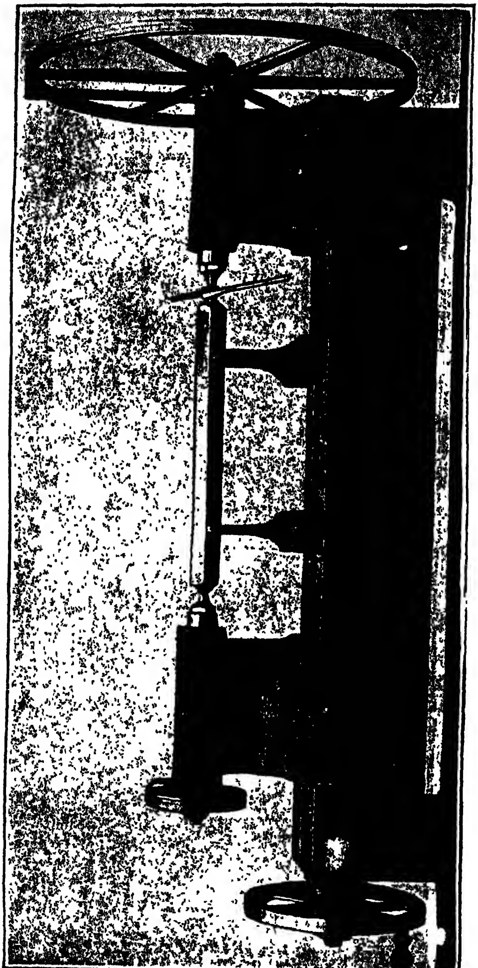


FIG. 7.—Whitworth Measuring Machine.

the large dividing wheel, one division of the latter representing .0001 in. end movement of the spindle. The movable head spindle is arranged to be adjusted to suit the length being operated upon, the divisions on the bed are to roughly set the headstock to the best position without having to try in the standard, and the divisions on the small wheel assist in adjusting the spindle, especially when it has been set too tight and requires easing back. In that case the division can be noted and the wheel eased back, and then brought up again within one or two divisions (as experience may dictate) of its previous position. The final movement of any of the screws must be such as moves the spindles towards one another.

Method of Using

Assume a gauge 5.9342 in. long is required. Move the headstock inwards and clamp it at about the 6-in. mark, put in the 6-in. standard bar on the two supports and the gravity piece (noting all are clear), set the large wheel to zero, the spindle projecting about .3 from headstock, and then move the small wheel round slowly until the parts nip the gravity piece, but only just as much as to allow it to fall with its own weight. (If gravity piece is held too tightly, ease back again as previously explained.) Now take out the standard, put in the new gauge, give the large wheel 1 revolution equal to .05 in., and continue the movement to the marking 342, when, if the new gauge is correct, the gravity piece should just fall as before.

If the new gauge required is over 6 in., as 6.0342, on removing the standard, make a complete revolution of the large wheel (spindle moving outwards) and bring it back to 342, when the machine is set for 6.0342 in.

In either case, of course, if the gauge is large, the gravity piece will be gripped before the reading is reached when the difference will show how much is wanted off the gauge. If at any time by over movement of either spindle the object has been heavily gripped with more force than will nicely hold up the gravity piece, it is well to ease off the measuring wheel and move up again.

The limit of error of the length gauges supplied is about .0001 in., and the above supposes that the gauge under test has more or less similar end surfaces ground square with the parts resting on the supports. When a rough bar gauge with rounded ends is required, the machine being set as before, the gauge can be passed between the faces by hand, the gravity piece resting on the support. Its error will not probably exceed .0002 in. if reasonable care is used.

Short, flat, or round ended gauges may be tried between the spindles by hand without the use of the gravity piece. The limit of error with the cylindrical gauges supplied with the machine is about .00005 in., and for use in their manufacture the vernier fitted to the measuring wheel is used, but only, of course, over short movements.

The Tool-Room Microscope

The instrument shown in Fig. 8 is by Messrs Cooke Troughton & Simms Ltd. of York and is intended for such purposes as measuring angles, lengths, and pitches. Its accuracy depends upon the standard block or slip gauges and large dial micrometers graduated to one ten-thousandth of an inch. It can therefore be relied upon to give accurate results throughout its life, as the measuring rods which are used in making all length measurements maintain their accuracy indefinitely, and can be readily checked by any standard method.

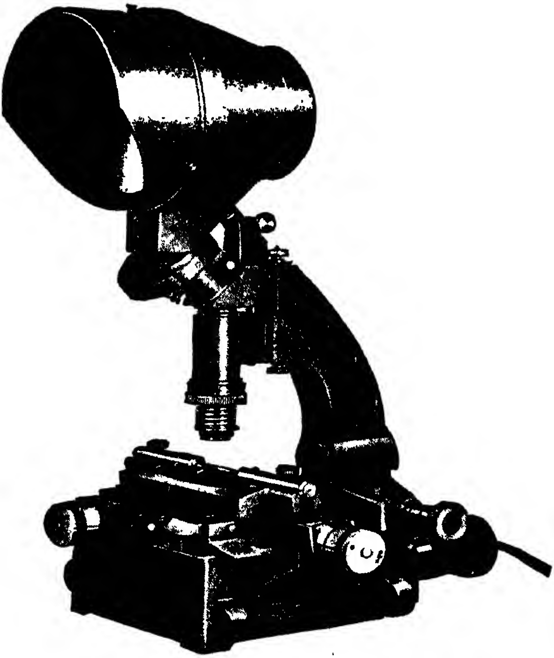


FIG. 8.—Tool Room Optical Machine.

The instrument consists essentially of a massive cast-iron stand carrying a worktable with movements in two directions at right angles and controlled by micrometer screws. The table also has a circular motion. The microscope, illumination apparatus, and projection attachment are mounted on a bracket inclinable about a horizontal axis in order that the screw thread, when under observation, may be viewed from a normal to the helix angle. The protractor and thread forms are engraved on glass and mounted in the focal plane of the eyepiece.

To the upper end of the microscope are attached units containing a protractor or screw thread forms, which are visible in the field of view and are superimposed over the image of the object under test.

The general conception of the design is of a robust character, whilst vital parts, such as slides, are well shielded or otherwise protected.

The applications of the instrument may be broadly summarised as follows :—

1. The determination of the relative position of two or more points on a piece of work by measuring the travel of the worktable necessary to transfer a second point to the position previously occupied by the first, and so on.
2. Measurement of angles by successively setting a fiducial line situated in the focal plane of the eyepiece along each arm of the image of the angle, or through points indicating the angle, and noting from a protractor scale the angle through which the fiducial line has been turned.

3. Comparison of thread forms with respect to outlines drawn on a glass plate situated at the focal plane of the microscope eyepiece and measurement of discrepancies therefrom.
4. Comparison of the enlarged projected image with a tracing drawn an exact number of times full size and affixed to the projection screen.

When possible the external boundary of the part is used for the purpose of measurement, and, as the light enters from beneath, the contour of the part is revealed as a silhouette when viewed through the microscope. In cases where this is not possible, as, for example, in measuring depressions in the surface of a solid object, the surface is illuminated from above.

The Optical System

The microscope presents to the eye an erect image, and in the vertical plane the movement of the image is in the same direction as the object, whilst in the horizontal plane it is the opposite. When the image is viewed on the projection screen it is inverted and the direction of its movement in the horizontal plane is the same as the object, whilst in the vertical plane it is the reverse.

Three objectives are available which give initial magnifications of $1\times$ (E815), $2.5\times$ (E816), and $5\times$ (E817), and they are calibrated so as to ensure that the magnification produced by each is exactly as stated, to within the limits of measurement of the instrument. This is essential, since the template forms which are placed in the focal plane of the eyepiece are used for comparative measurement and therefore, in conjunction with the objective magnification, must bear a dimensional

relationship to the object. The objectives are approximately parfocal, that is to say, they may be exchanged without appreciably affecting the focusing adjustment, but it should be noted that to engage the lowest power without disturbing the focusing adjustment it is necessary either to remove the glass plate in the table top or to disconnect the microscope body.

The eyepieces, one of which is included with each

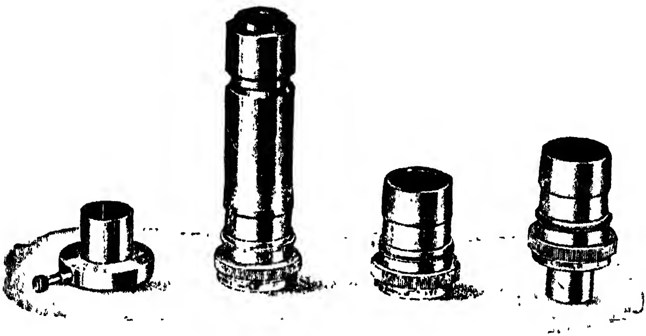


FIG. 9.—Objectives for Cooke's Workshop Microscope.

protractor and thread template unit, have a power of 10 ×, and in consequence the ultimate magnification yielded is 10 ×, 25 ×, or 50 ×, according to the objective used.

The projection attachment provides for screen magnifications also to be 10 ×, 25 ×, and 50 ×. The diameter of the area of object visible is with 10 × 0.8 in., with 25 × 0.3 in., and with 50 × 0.15 in. The projection attachment is secured to the microscope by a spigot fitting with clamp, and there is a locating key to ensure that the screen is correctly positioned with respect to the rest of the apparatus.

An episcopic illuminator is used on objects where a

silhouette cannot be obtained and consists of six small lamps arranged in a circle backed by a suitable ring reflector, the mount being attached to the microscope objective.

In order to avoid reflections which occasionally occur when observing cylindrical work a reflection occulter is provided for attachment to the microscope objective.

The Optical Bracket

The microscope, the projection attachment, and the illuminating apparatus within the base of the instrument are mounted on a single bracket which is supported in a horizontal bearing. The purpose of this arrangement is that in examining screw threads the whole of the optical system can be inclined away from a normal to the axis of the screw under measurement to the extent of the helix angle of the thread, that is to say, the optical axis of the microscope can be placed at a normal to the thread form. This movement is controlled by a micrometer screw whereby the optical system may be inclined to the desired angle (1 revolution = 1 degree, 1 division = 1 minute). Furthermore, when the work is supported between centres in cradle 1, the plane of measurement is common with the optical bracket bearing. This is not a condition essential to measurement, but it is a convenience in that in tilting the optical system to the correct helix angle the image of the screw as seen in the microscope does not move across the field of view.

The Travelling Worktable

Illustrations of the travelling worktable and the fittings for holding the work will be found on pages 23 and 24.

The longitudinal movement of the worktable is 4 in.,

and the transverse movement is 2 in., the longitudinal movement being situated below the transverse movement, whilst uppermost is a circular movement limited to 10° in either direction.

The linear movements of the table are controlled by micrometer screws each having a range of 1 in. and 40 threads per inch. The drums, which are 2 in. in diameter, are divided into 250 parts, consequently one division registers a movement of .0001 in. Measurement up to 4 in. and 2 in. respectively is obtained by the insertion of slip gauges between the micrometer and the carriage. The instrument is also supplied for metric measurement (see p. 11).

The tables are mounted on balls running in heat-treated slides and move with the utmost freedom and consistency. The moving elements are maintained in contact with the micrometers by light spring pressure as nearly uniform as possible over the length of travel. In order that no damage to a micrometer shall result from the sudden removal of a gauge block the speed at which the carriage can return to the micrometer is controlled by an air brake actuated through a clock mechanism. This is so adjusted that the carriage will just keep up with the anvil when the micrometer is turned rapidly.

In order to avoid damage to the slides during transport, clips are provided to relieve the balls and slides of the weight of the carriage.

The Protractor Unit

This unit, as in the case of each thread template unit, includes a 10 × eyepiece, which forms part of the optical system of the microscope. The unit connects with the body tube of the microscope by a spigot which is secured

by a clamp. It consists essentially of a glass disc suitably mounted and capable of rotation by a rack and pinion. A circular scale graduated and figured to 1° is engraved near the periphery of the disc. The circular scale is observed through a separate microscope, which also contains a fixed reticule having sixty lines to embrace 1° on the scale, thus the protractor scale is 1 division = 1 minute.

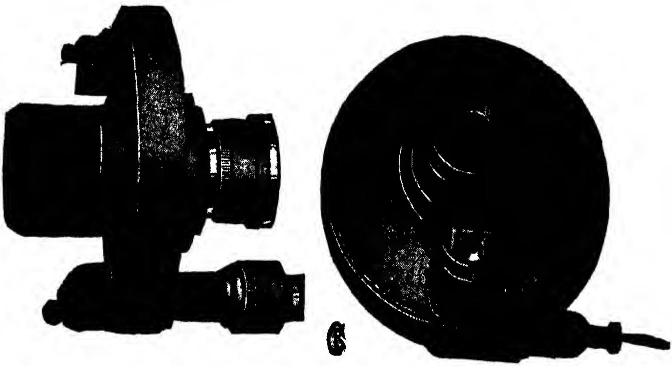


FIG. 10.—Protractor Unit for Workshop Microscope.

Coinciding with the centre of the protractor are fiducial lines, shown in the diagram, which are viewed through the microscope eyepiece and serve as index lines for setting the protractor on the parts to be measured.

It is necessary that the horizontal fiducial lines shall be parallel to the direction of travel of the worktable when the protractor reading is 0°, and this adjustment is secured by a rotary movement of the unit with respect to the microscope, for which an adjustable stop A is provided. For the purpose of facilitating this adjustment, a glass disc mounted in the table top has one line engraved

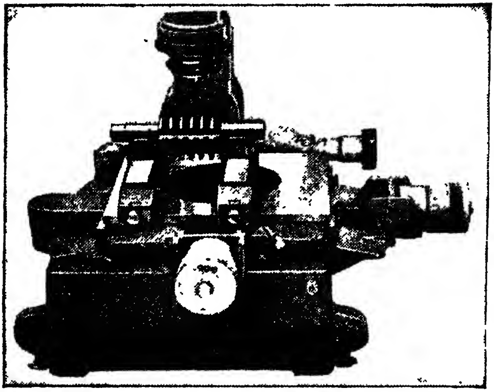


FIG. 11.—Close-up of an Optical Measuring Machine Checking a Hob.
(*By courtesy of Messrs Cooke Troughton & Simms Ltd., York.*)

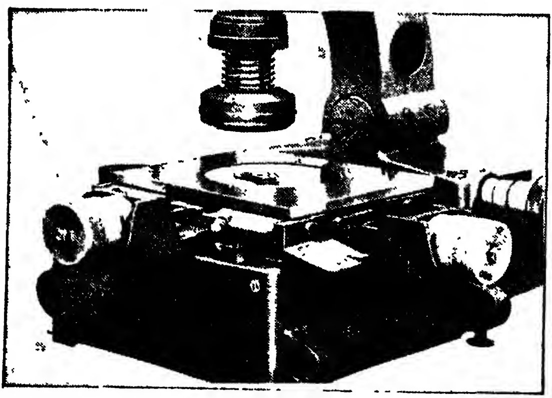


FIG. 12.—Close-up of an Optical Measuring Machine.
(*By courtesy of Messrs Cooke Troughton & Simms Ltd., York.*)

upon it. By observing this line against the fiducial line in the microscope and allowing the table to traverse, this line can be set parallel to the direction of travel. It then remains to set the protractor unit fiducial line parallel with the observed line at the table top.

With the projection attachment in position it is not possible to align the eye with the protractor scale microscope, and in consequence a cap B containing a prism is placed over this eyepiece, thus enabling the scale to be observed from a horizontal direction. The protractor microscope eyepiece has a spiral focusing adjustment and an independent illuminator.

The Thread Template Unit

In this unit the thread forms and other markings incidental to the use of the instrument are arranged around a glass disc, capable of rotation by rack and pinion motion and placed in the focal plane of the microscope eyepiece. At the edge of the field of view is a protractor scale reading 7° in either direction, part of which appears in the lower diagram on page 24. This is fixed relatively to the unit, and it serves as an index for setting the template, also to measure deviations from the correct thread angle or its position relative to the axis of the thread. This unit connects with the microscope body in the same manner as the protractor unit, but, in order that when using projection the figures are erect, it can be turned through 180°. It should be observed that this movement merely erects the figures, it does not alter the fact that the direction of movement of the image remains opposite to that of the object.

An example of checking a thread form is shown at Fig. 11, where a hob is shown mounted on a mandrel

and resting on V blocks fitted to the instrument table. The view of the field as shown through the microscope features at Fig. 13. When making the check either the

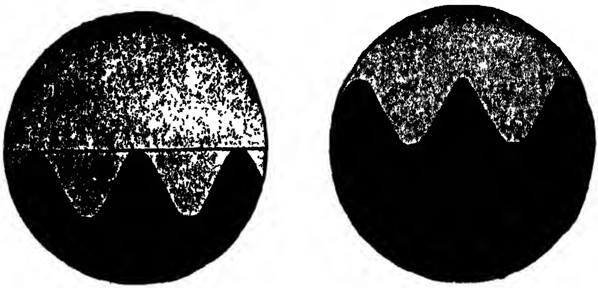


FIG. 13.—Measuring Thread Depths.

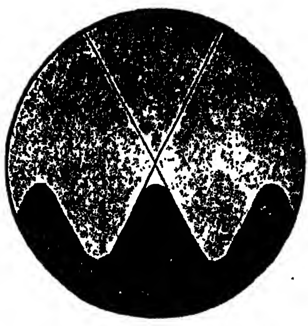


FIG. 14.—Thread Profile.

crest or root of the thread is adjusted until it lies exactly on the horizontal line. This done, the protractor is rotated until the profile of the thread is parallel to or exactly on the line vertical to the datum. Then the reading is taken.

To measure the depth of thread, adjust the work and the micrometer until the hair lines just touch the crest of the threads. Now move the compound slide until the hair lines just touch the roots of the threads—the micrometer then registers the depth of the thread. The method is shown in Fig. 14.

If using the thread template as supplied with the instrument, the profile of the thread may be checked in a somewhat similar manner to that illustrated at Fig. 15.

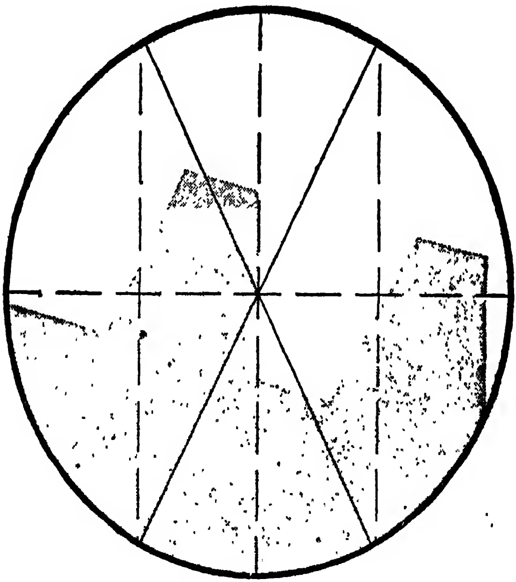


Fig. 15.—Episcopic Illuminator Attached to Microscope Objective for Use on Solid Objects.

Screw Diameter Measuring Machine

The machine shown in Fig. 16 has been designed to measure accurately, and with the utmost convenience, the outside, effective, and root diameters of screws.

The bed of the machine consists of a heavy box form casting, machined all over to relieve any internal stress. The top face is provided with a V groove and a T slot. The groove serves as a guide for the adjustment of the tailstock and the saddle upon which the micrometer frame slides.

The headstock carrying a fixed centre, shown to the left of the machine, is permanently fastened down, while the tailstock is free to slide along the bed, and can be clamped wherever required. The centre in the tailstock can be pushed in or out and clamped securely in position without upsetting the alignment. The tailstock is clamped by means of a lever which tightens a bolt inside the tenon groove.

The saddle is provided with two V grooves to accommodate two rows of steel balls, upon which the micrometer frame rests. This frame has a groove of the same shape as that on the saddle, and a flat which rests on another row of balls.

The micrometer is furnished with three anvils One of the anvils measures from zero to 1 in., another from 1 in. to 2 in., and a third allows measurements from $1\frac{1}{4}$ in. to $2\frac{1}{4}$ in. to be taken. In order to set the last two anvils correctly, suitable gauges are supplied. The head of the micrometer is adjustable to enable the operator to set the micrometer to zero.

A thimble carries a large graduated disc reading to .0001 in. Above the micrometer there is fixed an index pointer to read the graduations on the disc and a rod from which the wires are suspended.

Fig. 16.—Alfred Herbert's Screw Thread Measuring Machine.

Measurements

In order to check the thickness of any thread having a V form, use is made of the three wires or cylinders arranged as shown at Fig. 17. Now from the basic rules of geometry it is known that a cylinder of a suitable diameter will always lie at the same depth within the groove of an external thread of the standard form and thickness, the

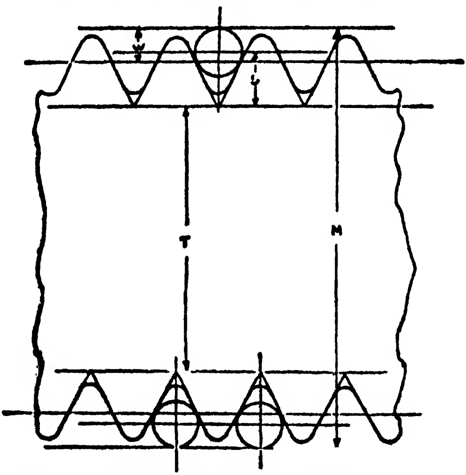


FIG. 17.—Three-Wire System of Measurement.

latter dimension normally being taken on the pitch or effective diameter. Conversely it follows that errors in either the form or thickness of the thread will alter the position of the roller within the groove.

Hence if three wires of the same diameter are placed in the position shown in Fig. 17, the measurement over the wires consists of the diameter T of the cylinder touched by the apexes of the thread angles below the root diameter,

plus twice the distance s from that point to the centre of one of the wires, plus the diameter w of one of the wires.

The first quantity for each nominal diameter of screw and number of threads per inch is constant, and the size of the wire being known, any departure from the overall reading must necessarily indicate a corresponding departure in the other dimension, *i.e.*, the distance s, which can only happen if the form of the thread and consequently the effective diameter is incorrect.

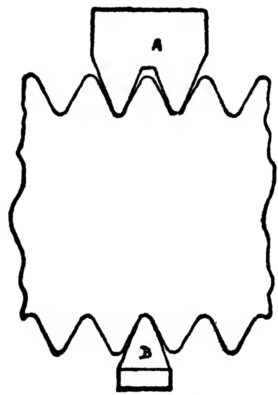


FIG. 18.—Measurement of Root Diameter.

The measurement of outside diameters is a comparatively simple matter, as the position of the micrometer in relation to the work ensures correct readings even with a two-point contact.

When measuring the root diameter of a thread two specially shaped anvils, as shown at Fig. 18, may be used; alternatively, three knife-edged anvils placed similarly to the rollers at Fig. 17 may be chosen. The drawback to the arrangement at Fig. 18 is that the anvil A must be made for each pitch, but when using three separate anvils of the same size a fair range of threads may be examined with the one set.

The adapters or anvils are made from a suitable grade of steel, correctly heat treated, then ground and lapped to both size and shape so that the knife edge makes contact at the root, leaving the sides clear of the flanks of the thread.

CONSTANTS FOR MEASURING PITCH DIAMETER OF THREADS

No. of Threads per inch	Value of 1.6008p	Value of 1.5155p	Value of 1.732p	Nos of Threads per inch	Value of 1.6008p	Value of 1.5155p	Value of 1.732p
60	.0267	.0253	.0289	10	.1601	.1515	.1732
56	.0286	.0271	.0309	9	.1779	.1684	.1925
48	.0334	.0316	.0361	8	.2001	.1894	.2165
40	.0400	.0379	.0433	7	.2287	.2165	.2474
32	.0500	.0474	.0541	6	.2668	.2526	.2887
30	.0534	.0505	.0577	5½	.2911	.2755	.3149
28	.0572	.0541	.0619	5	.3202	.3031	.3464
25	.0640	—	—	4½	.3557	.3368	.3849
24	.0667	.0631	.0722	4	.4002	.3789	.4330
22	.0728	.0689	.0787	3½	.4574	.4330	.4949
20	.0800	.0758	.0866	3¼	.4926	.4663	.5329
18	.0889	.0842	.0962	3	.5336	.5052	.5774
16	.1001	.0947	.1083	2⅞	.5568	.5271	.6025
15	.1067	.1010	.1155	2¾	.5821	.5511	.6298
14	.1143	.1082	.1237	2⅝	.6098	.5773	.6598
13	.1231	.1166	.1332	2½	.6403	.6062	.6928
12	.1334	.1263	.1443	2⅜	.6740	.6381	.7293
11	.1455	.1378	.1575	2¼	.7115	.6730	.7698

TABLE I.

For measuring the pitch diameter the following formula can be used :—

$$M = T + 2S + W,$$

in which M, Fig. 17, is the dimension over the wires, D is the nominal diameter of the screw, T is the diameter of the cylinder as given by the intersection of the straight lines off the flanks of the thread, S is the distance from the outside of that cylinder to the centre of the roller or wire, and W is the diameter of the wires. As obtained from the manufacturers, each set of wires is accurately made and of the same cross-sectional dimension.

For Whitworth standard threads - $M = D - 1{\cdot}6008P + 3{\cdot}1657W$.
,, U.S. or metric if pitch in inches $M = D - 1{\cdot}5155P + 3W$.
,, Sharp V threads - - - $M = D - 1{\cdot}732P + 3W$.

The wires must not be smaller than $\cdot 506P$ or larger than $\cdot 840P$ where $P = \frac{1}{\text{number of threads}}$.

The values of constants used in the formulas for measuring pitch diameters are given in Table I.

CHAPTER II

MEASURING TOOLS

In the workshop the most commonly used measuring instrument is the rule. However, for precision work, the micrometer is the basic piece of equipment as used by the craftsman for determining the size of various classes of work.

In order to understand the principle upon which the micrometer is based, it is necessary to understand the meaning of the word "pitch" as it is applied to the screwed thread. This can be best understood by actually handling a screw and nut, and demonstrating that the nut or screw will in one revolution move a distance equal to the distance between the centre of one thread and the centre of the next turn of the thread measured in a line with the axis of the screw.

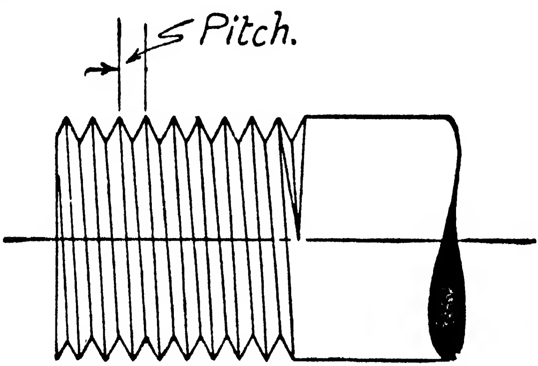


Fig. 19.—Screwed Thread.

Fig. 19 illustrates a single start thread. If the distance between the thread centres is $\frac{1}{8}$ of an inch, then the pitch is $\frac{1}{8}$ of an inch; and if the screw is revolved one complete revolution, in a fixed nut, it will move an axial distance of $\frac{1}{8}$ of an inch. It also follows that one-half of a revolution would move the screw a distance equal to one-half the pitch or $\frac{1}{16}$ of an inch, and whatever fraction of a revolution is given to the screw it will move a distance equal to that fraction of the pitch. For example, a screw having forty threads per inch would have a pitch of $\frac{1}{40}$ of an inch, and if turned in a nut one-tenth of a revolution it would have moved $\frac{1}{10}$ of $\frac{1}{40}$ or $\frac{1}{400}$ of an inch.

Outside Micrometers

The type of micrometer generally used in the engineering workshop is shown in Fig. 20. This will read to one-

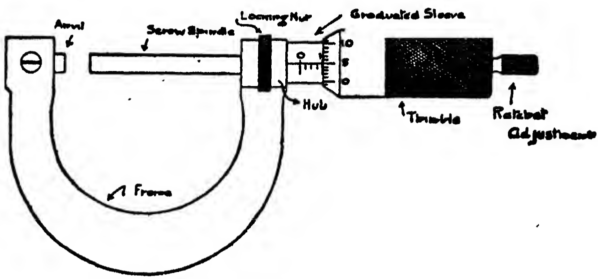


FIG. 20.—English Reading Micrometer.

thousandth of an inch (.001), and when provided with a vernier to one ten-thousandth of an inch (.0001).

The construction of the various parts will be seen in Fig. 21. The screw thread is enclosed and rendered dust proof,

and the wearing parts are hardened, with suitable provision for taking up any wear. A knurled locking nut contracting a split bush round the spindle will tighten and keep the

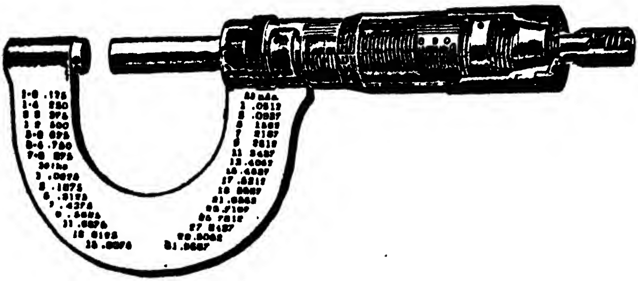


FIG. 21.—Construction of Micrometer.

spindle central and true, or by a slight turn it will lock the spindle firm, making a solid gauge when required.

The pitch of the screw in practically every make of English reading micrometer is forty threads per inch, or a

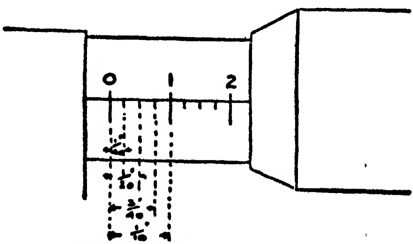


FIG. 22.—Graduations on Sleeve of Micrometer.

pitch of one-fortieth of an inch. The graduations on the sleeve in a line parallel to its axis are forty to one inch, and these graduations coincide exactly with the pitch of the screw; they are numbered every fourth division, 0, 1, 2, 3

up to 10, in the manner shown in Fig. 22. As these graduations conform exactly to the pitch of the screw, each division must equal the longitudinal distance traversed by the screw in one complete revolution, and would show that the screw had been moved $\frac{1}{40}$ of an inch (.025).

The bevelled edge of the thimble is graduated into twenty-five equal parts, as shown in Fig. 23; in this case every fifth

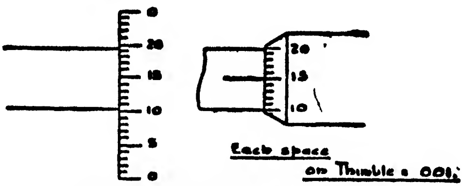


FIG. 23.—Graduations on Thimble.

division is numbered. Each division represents a movement of one twenty-fifth of the pitch of the screw, or $\frac{1}{25}$ of $\frac{1}{40}$, and would indicate a movement of $\frac{1}{1000}$ (.001).

To Read the Micrometer

It is necessary, before attempting to read the micrometer, to make a mental note of the following decimal equivalents:—

1 division on the barrel equals			$\frac{1}{40}$	of an inch	=	·025.
2 divisions	,,	,,	$\frac{1}{20}$	,,	=	·05.
3 ,,	,,	,,	$\frac{3}{40}$	,,	=	·075.
4 ,,	,,	,,	$\frac{1}{10}$	,,	=	·1.

Thus, every fourth figure from zero equals a certain number of tenths of an inch. To read the micrometer take the graduations in the following order:—

1. The number of tenths showing on the graduated sleeve.
2. The number of fortieths showing on the graduated sleeve.
3. The number of thousandths showing on the bevelled thimble.

Examples.—A simple example is given in Fig. 24. Here it will be seen that the zero mark on the thimble is exactly

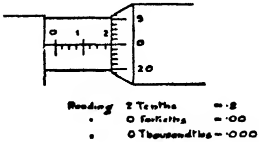


FIG 24.
Micrometer Reading.

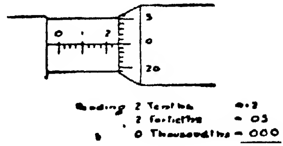


FIG. 25.
Reading in Tenths and Fortieths.

over the second tenth on the barrel, and therefore the reading would be two-tenths (.2).

In the example shown in Fig. 25, the reading is two-tenths, plus two-fortieths, or .2 + .05 = .250.

Another example is given in Fig. 26. This shows a reading of two-tenths, plus no fortieths, plus five-thousandths, or .2 + .005 = .205.

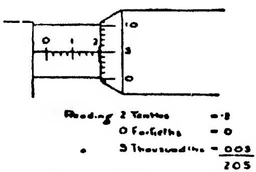


FIG. 26.
Reading in Tenths, Fortieths, and Thousandths.

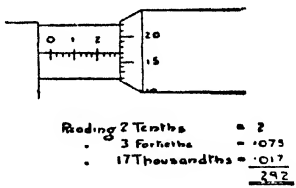


FIG. 27.
Micrometer Reading.

The next example, Fig. 27, gives a reading of two tenths, plus three-fortieths, plus seventeen-thousandths, or .2 + .075 + .017 = .292.

Bench Micrometer

An extremely useful type of bench micrometer is shown in Fig. 28. It is made with a stiff, heavy base, and can be

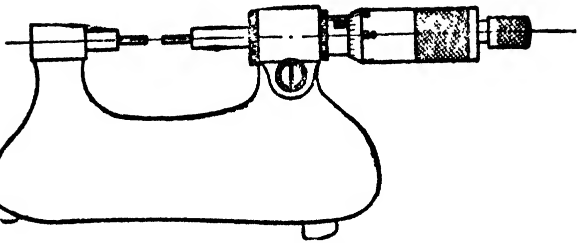


FIG. 28.—Bench Micrometer.

bolted to the bench. It is useful for taking fine measurements on work of such a character that can be best measured and inspected at the bench.

Micrometer with Vernier

A micrometer to read ten-thousandths of an inch is partly shown in Fig. 29. The readings finer than

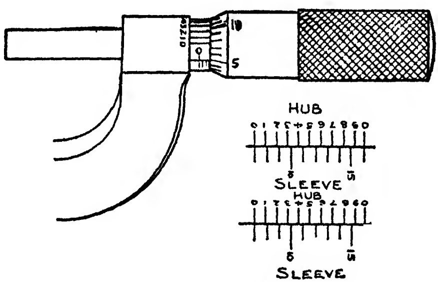


FIG. 29.—Vernier Micrometer.

thousandths are obtained by means of a vernier or series of division lines drawn on the sleeve of the caliper. These divisions are ten in number, and they occupy the same space as nine divisions on the thimble, as shown in Fig. 30, with the result that each space of the vernier is one-tenth smaller than a space on the thimble; therefore, if the first or zero line of the vernier coincides with any line on the thimble, then the last line of the vernier will do

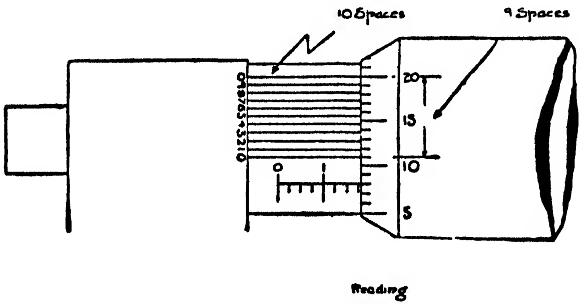


FIG. 30.—Graduations on Sleeve of Vernier Micrometer.

so as well. Starting from zero on the vernier, shown in Fig. 30, it will be seen that line number 1 stands away from a line on the thimble by one-tenth, line 2 by two-tenths, line 3 by three-tenths, and so on, until line 10 coincides with a line exactly.

Reading the Micrometer

To read the vernier micrometer, proceed as with the ordinary micrometer reading in thousandths; that is, note the tenths, fortieths, and thousandths, then see if the zero

line of the vernier coincides with any line on the thimble; if it does, then no ten-thousandths have to be added; if

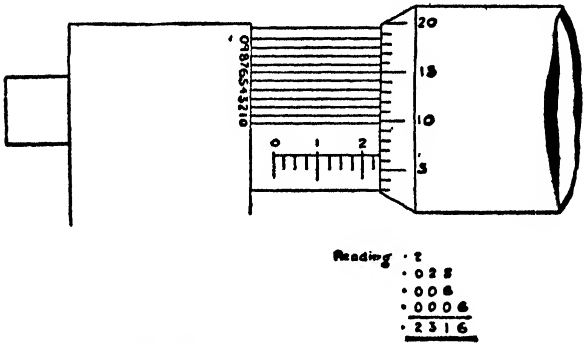


Fig. 31.—Micrometer Vernier Reading.

it does not, then find the line which does, and the number of the line will indicate the number of ten-thousandths to be added.

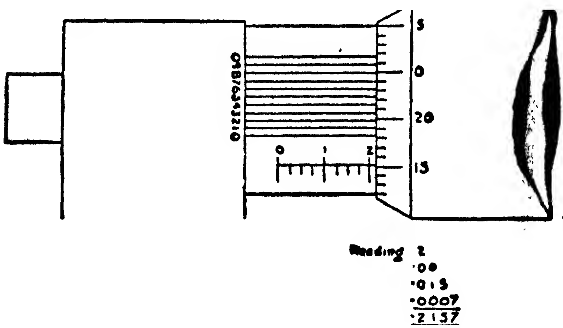


Fig. 32.—Example of Vernier Reading.

Examples.—The example given in Fig. 30 shows that the micrometer is open one-tenth, plus three-fortieths, plus eight-thousandths, or .1 + .075 + .008 = .183. As the zero line of the vernier coincides with a line on the thimble, no ten-thousandths have to be added. The reading of the example given in Fig. 31 gives two-tenths, one-fortieth, six thousandths, and six ten-thousandths, or .2 + .025 + .006 + .0006 = .2316.

Another example is given in Fig. 32. This would read two-tenths, no fortieths, fifteen-thousandths, and seven ten-thousandths, or .2 + .0 + .015 + .0007 = .2157.

Metric Micrometers

The metric reading micrometer is constructed on exactly the same principle as the English reading micrometer, the only difference being in the pitch of the screw and the marking of the graduations on the sleeve and thimble. The pitch of the screw is one-half a millimetre (½ mm.),

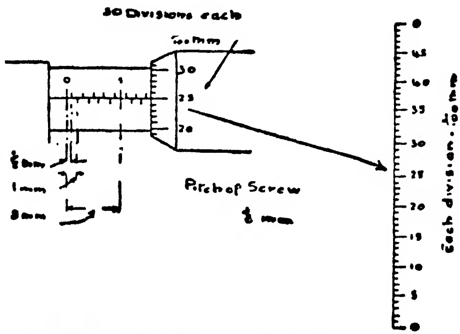


Fig. 33.—Graduation on Sleeve and Thimble of Metric Micrometer.

and the graduations on the sleeve and thimble are as shown in Fig. 33. Below the horizontal line on the sleeve, graduations are made every millimetre, with a long line every fifth millimetre reaching above the horizontal line; above the horizontal line graduation marks are placed so as to just split the millimetre divisions in half, as shown in the illustration.

The thimble is divided equally into fifty parts, every fifth division mark being lengthened and marked. A division on the thimble gives a reading of one-fiftieth of one-half of a millimetre or $\frac{1}{50} \times \frac{1}{2} = \frac{1}{100}$, or one-hundredth of a millimetre.

To Read the Micrometer

First note the number of millimetres to the left of the bevelled edge of the thimble, then see if one-half a millimetre is showing in addition, or not, and finally note the number of hundredths of a millimetre indicated by the thimble reading.

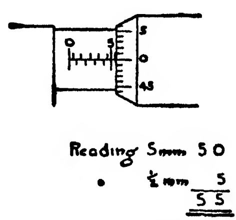


FIG. 34.—Readings on Metric Micrometer.

Examples.—The example given in Fig. 34 shows that the micrometer is open 5 millimetres, 1 one-half millimetre, and 0 hundredths of a millimetre, or 5 mm. + $\frac{1}{2}$ mm. = 5.5 mm.

In Fig. 35 the reading is 6 millimetres, 1 one-half millimetre, and 5 hundredths of a millimetre, or 6 mm. + .5 mm. + .05 mm. = 6.55 mm.

The next example, Fig. 36, gives 8 mm. + .5 mm. + .45 mm. = 8.95 mm.

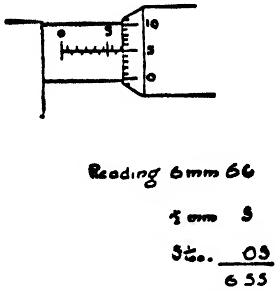


FIG. 35.—Metric Readings.

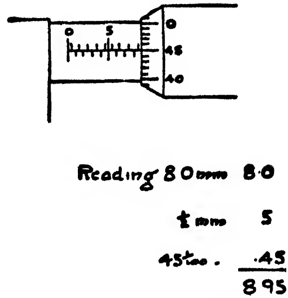


FIG. 36.—Metric Readings.

Internal Micrometers

When internal linear measurements of greater accuracy than can be obtained with the rule and caliper are required, they can be obtained by means of the internal micrometer. The smallest internal micrometer in common use will measure a minimum of ½ in. Below this size it is necessary to use gauges. A very good type of micrometer for internal measurements of fairly large size is shown in Fig. 37. With

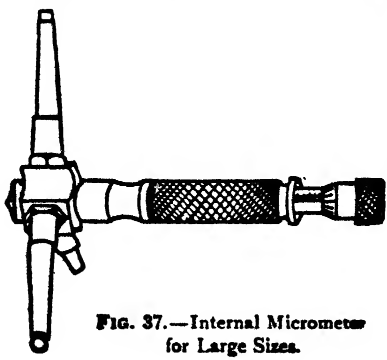


FIG. 37.—Internal Micrometer for Large Sizes.

this instrument the operation of measuring a cylindrical hole is as simple as taking a measurement with the ordinary micrometer caliper.

The tool has three measuring points, which are hardened and ground in their outer ends to spherical form, the diameter of this sphere being just below the smallest diameter in the range of the micrometer. The three points are operated by means of a screwed spindle, contained in the body of the tool, having an enlarged conical end, which makes contact with the inner ends of the three legs; as the spindle is moved forward the legs are thrust outwards until they touch the side of the hole desired to be measured. The thimble, operating the spindle, is graduated to .001 in., or .01 mm.

Another type of micrometer, but useful for holes of comparatively small diameter, is shown in Fig. 38. The barrel

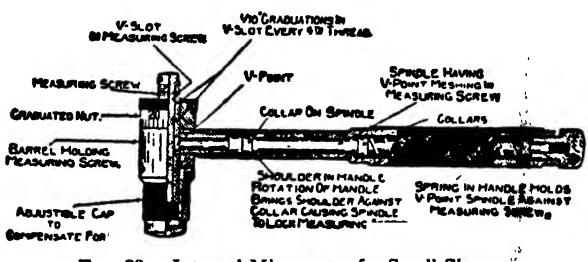


FIG. 38.—Internal Micrometer for Small Sizes.

or body of the instrument holds the measuring screw, which telescopes into the same. The measuring screw is advanced from the barrel by means of the graduated nut. There is an adjusting cap fitting on the opposite end of the barrel, and this is capable of adjustment to compensate for wear. The measuring screw is prevented from rotating when being advanced by the nut by means of the spindle in the handle

having a V point, and being held in position by the bushing which is threaded into the side of the barrel.

The reading of the micrometer is substantially the same as with the ordinary outside micrometer, the graduated nut corresponding with the thimble, and one-tenth division cut in the groove of the screw, together with the tops of the threads corresponding with the linear graduations of the sleeve. The one-tenth graduations are cut from the bottom of the groove to the top point of the thread, and appear every fourth thread.

Sliding Vernier Caliper

A front view of a sliding vernier caliper is shown in Fig. 39. It is graduated for English measurement, the

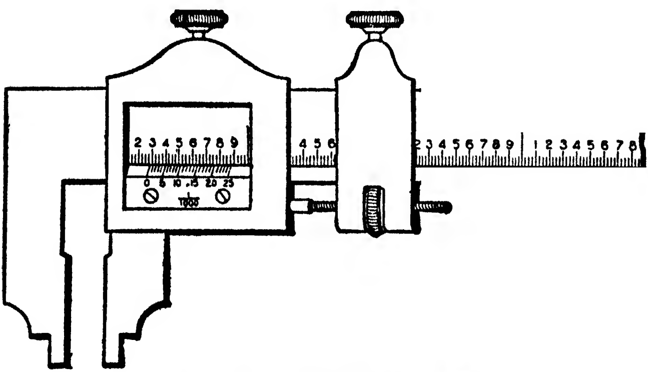


FIG. 39.—Sliding Vernier Caliper.

divisions on the beam being forty to the inch, which, together with the vernier, give a reading of one-thousandth of an inch, .001.

The Vernier Scale

The vernier was invented about the year 1630 by a Frenchman of the name of Pierre Vernier, and consists of an auxiliary scale attached to a main scale of a measuring instrument.

The principle on which the vernier is based is as follows: If a scale of one inch in length is taken and equally divided into ten parts, and if a length equal to nine of these spaces is taken and divided into ten equal parts, the result will be that each of the latter will be one-tenth shorter than each of the former. From Fig. 40 it will be seen that, commencing from zero and calling the top scale the beam and the bottom one the vernier, the second line of the vernier differs from the second line of the beam by one-tenth, and the third line of the vernier differs from the third line of the beam by two-tenths, and so on until the last line of the vernier exactly coincides with line ten of the beam, or in all a gain of one space over the length of the vernier.

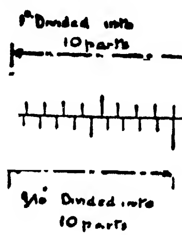


FIG. 40.—Vernier Graduations.

The vernier scale, as applied to the sliding caliper, gives readings which can be found as follows: first, find the number of graduations per inch on the beam, and then the number of spaces on the vernier, and the smallest measurement possible is the product of the former fraction and the latter.

Example.—If 1 in. is divided into twenty equal parts, and the vernier has ten equal spaces, then the minimum reading will be $\frac{1}{20} \times \frac{1}{10}$, or $\frac{1}{200}$ of an inch. If the inch is divided into forty divisions and the vernier into

twenty-five divisions, then the reading will be $\frac{1}{40} \times \frac{1}{25} = \frac{1}{1000}$, or $\frac{1}{1000}$ of an inch.

Vernier Scale Readings

In Fig. 41 a vernier and beam are shown enlarged; to read this, first note how many inches, tenths. and fortieths the zero line on the vernier is from the zero line of the

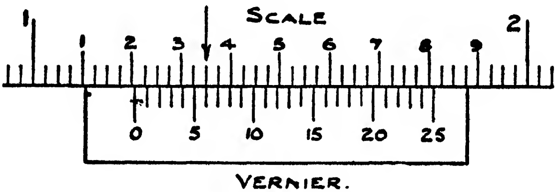


Fig. 41.—Graduations on Vernier and Beam.

beam; then note the number of divisions from zero on the vernier to the first line of the vernier coinciding with a line on the beam. In the example given the reading would be—

1 inch	=	1·0
2 tenths	=	·2
0 fortieths	=	·0
vernier	=	.006
		1·206

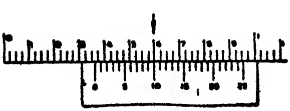


Fig. 42.
Vernier Caliper Reading.

Examples.—The readings of Fig. 42 would be no inches, plus three-tenths, plus two-fortieths, plus ten-thousandths, or .3 + .05 + .01 = .360.

In the example, Fig. 43, the readings are one inch, plus two-tenths, plus three-fortieths, plus seventeen-thousandths, or $1.0 + .2 + .075 + .017 = 1.292$.

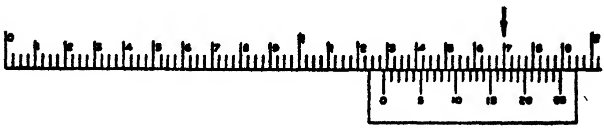


FIG. 43.—Sliding Vernier Caliper Reading.

The Bevel Protractor

Many varieties of protractors are made for measuring angles; the one shown in Fig. 44 consists of a graduated disc with a fixed blade and adjustable stock. It is well adapted for all classes of work where angles are to be laid out or measured to within the limits of 5 minutes. One side of the stock is flat, thus permitting its being laid flat upon the work. The dial is graduated in degrees over an arc of 180° reading 0° to 90° from each extremity of the arc. The verniers are so placed with relation to the graduated half-circle as to make the protractor readable by vernier in any position, the readings being one-twelfth of a degree.

Vernier Scale adapted for Angular Measurements

The vernier shown in Fig. 44 is graduated to read to one-twelfth of a degree, or 5 minutes, this being fine enough for most workshop purposes. Each space on the vernier is 5 minutes shorter than two spaces on the true scale. When the line 0 on the vernier coincides with the line marked 0 on the true scale, the edges of the base and blade

are parallel. When the swivel head is moved so that the line on the vernier next to o coincides with the line next but one to o on the true scale, the included angle of the base and blade has been changed one-twelfth of a degree.

In order to take a reading from the protractor, first read off directly from the true scale the number of whole degrees

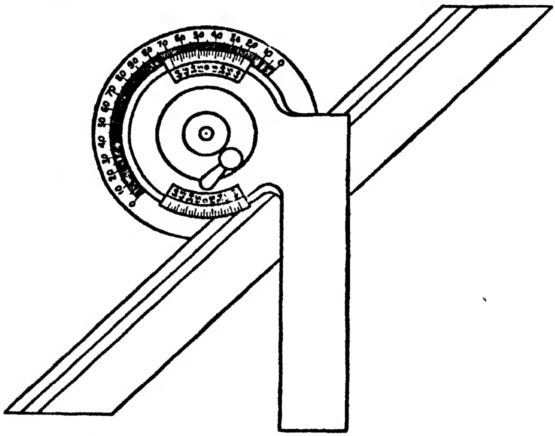


FIG. 44.—Bevel Protractor with Vernier Scale Attachment.

between o and the o of the vernier scale; then count in the same direction the number of spaces from zero of the vernier scale to a line which coincides with a line on the true scale; multiply this number by 5, and the product will be the number of minutes to be added to the whole number of degrees.

Examples.—From the example shown in Fig. 45 it will be seen that the number of degrees between zero on the

disc and zero on the vernier is 30. The line numbered 45 on the vernier coincides exactly with line 50 on the disc, and as nine spaces occur between zero on the vernier and

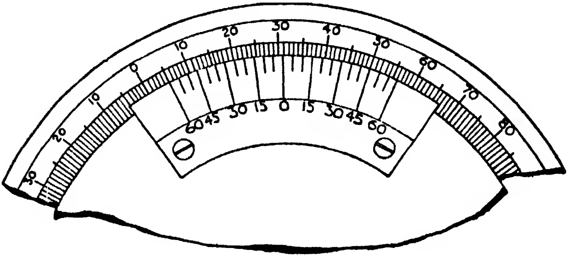


Fig. 45.—Vernier Scale Readings on a Protractor.

the coinciding line, then the reading in minutes will be $9 \times 5 = 45$. Thus the protractor would read $30^\circ\ 45'$.

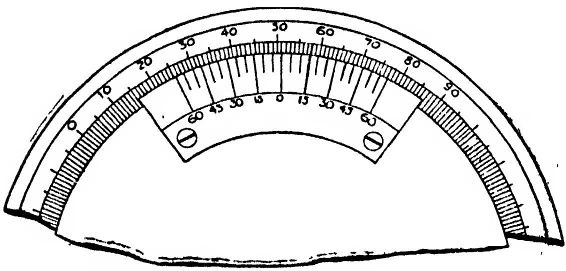


Fig. 46.—Vernier Scale Readings on a Protractor.

In the example shown in Fig. 46 the reading would be $50^\circ\ 15'$, the number of degrees between zero on the disc and zero on the vernier being 51, and the number of spaces between 0 on the vernier and the coinciding line being 3.

Application of Protractor

The examples shown in Fig. 47 illustrate some of the various uses to which the bevel protractor can be applied.

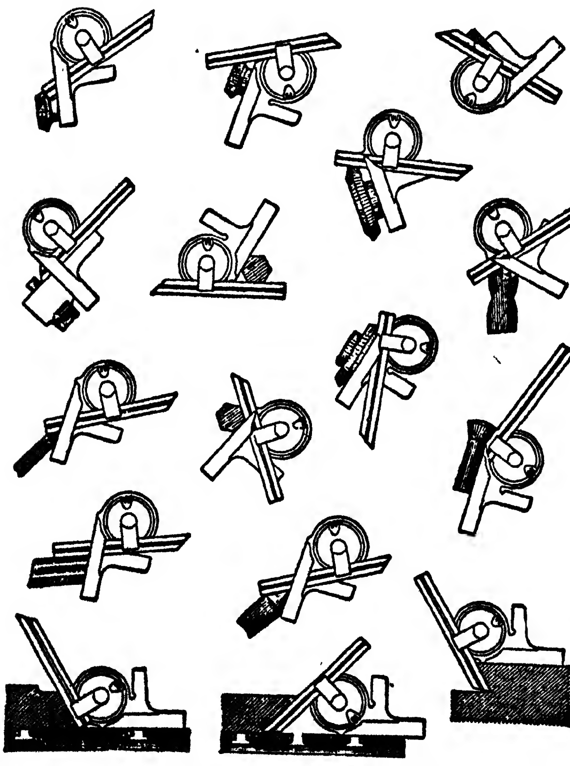


FIG. 47.—Method of using Bevel Protractor.

The Sine-Bar

When it is not possible or it is inconvenient to use the bevel protractor for setting out or measuring angles, the sine-bar can often be conveniently used.

The sine-bar, one design of which is shown at Fig. 48, is of a very simple construction and consists of a bar and two pins or plugs. It is a precision instrument, and the distance between the centres is usually of even dimensions

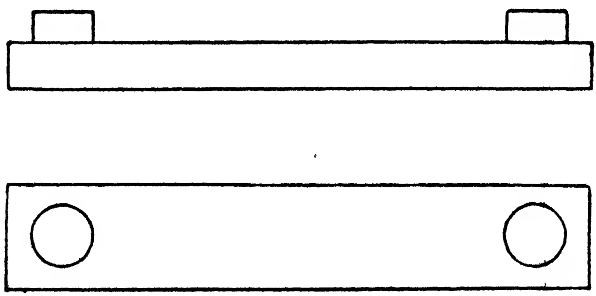


FIG. 48.—Sine-Bar.

to facilitate calculations, preferably of such a dimension as 5 or 10 in.

In order to use the sine-bar it is necessary to work from a flat surface as a base for the work and the instrument. The principle on which the bar is based will be seen in Fig. 49; this represents a right-angled triangle, and if A is the angle to be measured, a will be termed the opposite side, b the adjacent side, and c the hypotenuse. To find the sine of A it is necessary to divide the opposite side by the hypotenuse, or in formula—

$$\text{Sine A} = \frac{a}{c}.$$

Thus, if the length of *a* is 4 in., and the length of *c* is 6 in., then the sine of A would be $4 \div 6 = .6667$.

To find the angle after obtaining the sine, a table of sines can be referred to. This would give the angle A as $41^\circ\ 49'$.

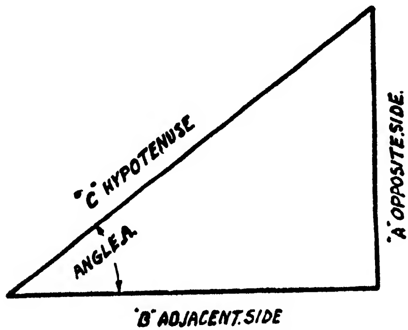


FIG. 49.—Right-Angled Triangle.

In using the sine-bar, the distance between the stud centres can be considered to equal the length of the hypotenuse of the triangle, and the difference in the heights of the studs above the base plate can be considered as the length of the opposite side.

Measuring an Angle

If it is desired to find the angle formed between a line on a piece of work and a base, it is necessary to place the edge of the sine-bar parallel with the line to be measured in the manner shown in Fig. 50; heights *a* and *b* are then carefully taken by means of the standard gauge blocks or a height gauge. If height *b* is then subtracted from height *a* the result can be considered as equivalent to the length of the opposite side of a right-angled triangle, and the sine of the

angle would be the difference in heights *a* and *b* divided by the distance between the centres of the studs in the sine-bar.

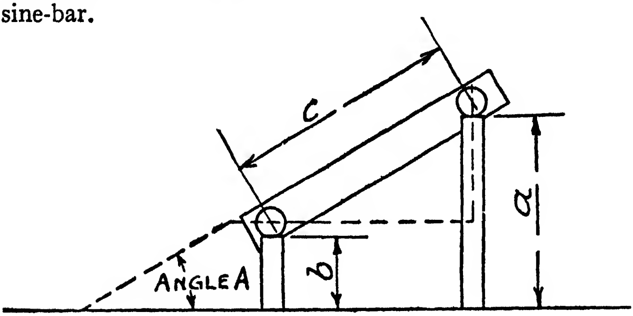


FIG. 50.—Sine-Bar Measurements.

Example.—If height *a* is 3.75 in., and *b* 1.25 in., and *c* 5.0 in., then the sine of A would be $(3.75 - 1.25) \div 5 = 0.5$, and the angle would be 30°.

Setting Out an Angle

In setting the edge of the bar to a determined angle, it is necessary to find the difference in heights *a* and *b*; this can be found by multiplying the sine of the angle by the length *c*.

Example.—Set out an angle of 30° from a point $1\frac{1}{4}$ in. from a common base, length of *c* being 5 in. Then sine of $30° = .5$, $.5 \times 5 = 2.5$, the difference in heights equals 2.5, therefore the heights *a* and *b* would be 1.25 and 3.75.

Measurement of Tapers

To find the angle for a given taper per foot, divide the taper in inches per foot by 24. The result is the tangent

of the angle measuring off the centre line and the angular dimension is taken from a set of trigonometric tables. Doubling the value obtained gives the included angle.

Example.—Find what included angle is equivalent to a taper of 1¼ in. per foot.

$$\text{Then,}\quad \frac{1{\cdot}25}{24} = {\cdot}05209.$$

The angle for this tangent is 2° 59′; this multiplied by 2 gives an included angle of 5° 58′.

Rules for Finding Tapers

Given.	To Find.	Rule.
The taper per inch	The taper per foot	Multiply the taper per inch by 12
The taper per foot	The taper per inch	Divide the taper per foot by 12
End diameters and length of taper in inches	The taper per foot	Subtract small diameter from large; divide by the length of the taper, and multiply the quotient by 12
The taper per foot	Amount of taper in a certain length given in inches	Divide taper per foot by 12; multiply by given length of tapered part
Small diameter and length of taper in inches, and taper per foot	Diameter of large end in inches	Divide taper per foot by 12; multiply by length of taper, and add result to small diameter
Large diameter and length of taper in inches	Diameter at small end in inches	Divide taper per foot by 12; multiply by length of taper, and subtract result from large diameter
The taper per foot and two diameters in inches	Distance between two given diameters in inches	Subtract small diameter from large; divide remainder by taper per foot, and multiply quotient by 12

Depth Gauges

This tool is used to measure the depth of blind holes, the distance from a plane surface to a projection, and work of a similar character. The simplest form is as shown in Fig. 51, which consists of a narrow steel rule fitting into a cross foot piece, being adjusted by hand and held in position by means of a small knurled screw.

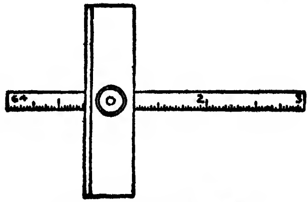


FIG. 51.—Depth Gauge.

A more accurate tool is shown in Fig. 52. This is a valuable instrument where accurate measurements are

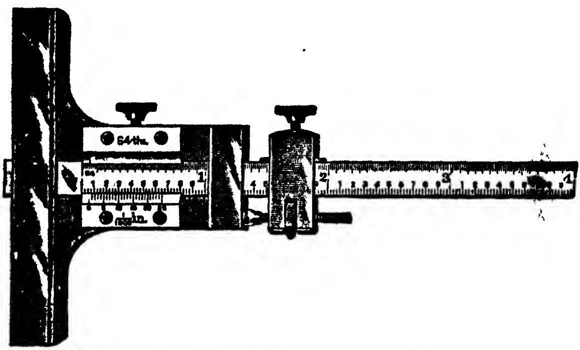


FIG. 52.—Vernier Depth Gauge.

necessary. The blade is graduated into fortieths of an inch on one edge, and to sixty-fourths of an inch on the other. By means of the vernier scale it is possible to take readings of one-thousandth of an inch.

This type of gauge can be obtained graduated to read by means of a vernier scale to one-fiftieth of a millimetre on one side and to thousandths of an inch on the other side.

Gear Tooth Caliper

When cutting gear wheels it is necessary to measure occasionally the distance from the top of a cut tooth to the pitch line, and also the thickness of the tooth at the pitch line. By using the tool shown in Fig. 53, compensation can often be made for any variation or error in the size of the blank.

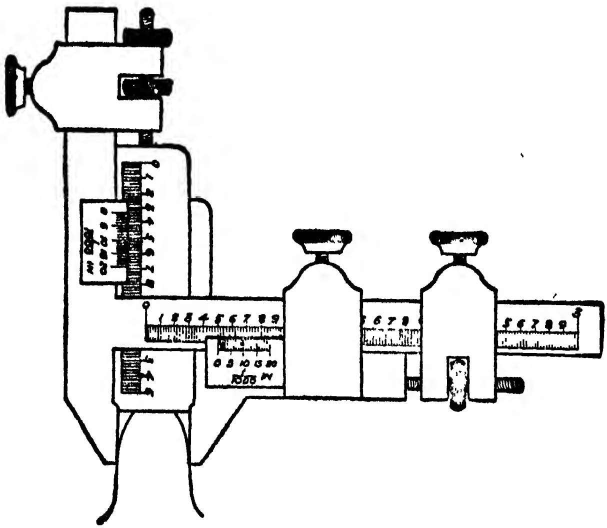


FIG. 53.—Gear Tooth Caliper.

The sliding jaw of the caliper moves on a bar graduated to read, by means of a vernier, to thousandths of an inch. A tongue piece, moving at right angles into the jaws, is graduated in the same manner. Both the sliding jaws and tongue piece are provided with adjusting screws. The caliper is specially needed when any doubt exists as to the exact size of the wheel blank. To test the tooth thickness, a trial cut is taken for a short distance on one side of the blank; then the blank is moved round for the next cut, after which another trial cut is taken for a part of the distance across the gear. The vertical scale of the caliper is then set, so that when it rests on the top of the tooth the lower ends of the caliper jaws will be in line with the pitch circle. The horizontal scale then shows the chordal thickness of the tooth. When a gear is measured in this manner the chordal thickness is obtained, and not the length measured along the pitch circle. Hence, when measuring teeth of coarse pitch, especially if the diameter of the gear is small, dimension T in Fig. 54 should be obtained. It is also necessary to find the height x of the arc, and add it to the addendum S to obtain the correct height H, in order to measure the chordal thickness T at the proper point on the sides of the tooth.

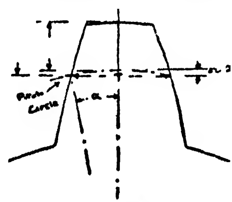


FIG. 54.
Chordal Thickness of Teeth.

If a equals one-half of the angle subtended at the centre of the gear by one gear tooth,

N = number of teeth in gear.
T = chordal thickness of tooth at pitch line.
R = pitch radius of gear.

Then, $a = 90^{\circ} \div N$; $T = 2R \times \sin a$.

The height x of the arc equals 1 minus the cosine of the angle α, multiplied by the pitch radius of the gear, or, expressed as a formula, $x = R(1 - \cos \alpha)$. The vertical scale of the caliper is set to H or x + addendum S.

Dial Gauge

A very useful tool for ascertaining measurements tc a fine degree of accuracy is shown in Fig. 55. This is termed

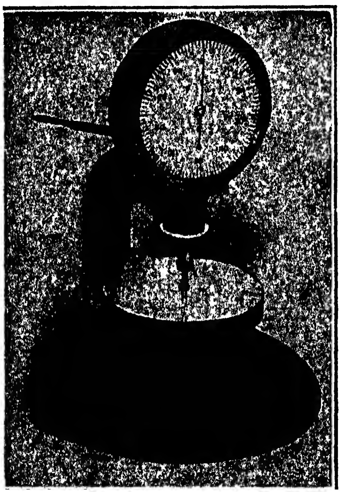


FIG. 55.—Dial Test Gauge.

a dial gauge. The dial is fixed, and is provided with a movable scale in order to adjust to zero; readings can be taken in thousandths of an inch.

CHAPTER III

GAUGES AND GAUGE SYSTEMS

The successful output of work from the modern engineering shops depends so much upon interchangeability that some system of working to gauges is necessary. Rapidity of production, lessened supervision, elimination of the human factor in judging sizes, and reduction in the amount of spoiled work, and the need under arduous service conditions to replace worn or broken components are all factors tending to make the use of some means or methods for controlling sizes during the process of manufacture of utmost importance.

The Newall System

When preparing a general system of limits it is necessary to decide in which direction the necessary variations away from the nominal dimension are to be made. The Newall system works upon what is termed the "hole basis." Hence the dimensional accuracy of the hole is held within fine limits (see table on p. 63), and in order to obtain the desired fit between the two mating parts the size of the shaft is varied. In each instance the limiting dimensions of the part fitting in the bore is determined according to its function.

The practice of working to limit gauges, and so defining and determining the amount of variation from gauge sizes, is now almost universal in the engineering trade. The advantages are so great that, in spite of the large initial cost, the economies produced by the system very soon compensate for the capital outlay.

It will be admitted that it is easier to vary the size of a shaft than that of a hole, and it is for this reason that the "hole basis" is chosen in preference to a "shaft basis." The majority of holes in engineering work are produced with drill and reamer or some similar tool, and to vary the size of holes would necessitate the use of a very large number of tools of varying sizes. The cost of producing an internal limit gauge for a hole is also greater than that of an external limit gauge, and for these reasons the "hole basis" is usually chosen as the most desirable system. In some classes of work, however, notwithstanding the increased cost, the "shaft basis" is more desirable.

Allowance

Allowance is the necessary difference in the sizes of two pieces of work in order to obtain the particular quality of fit required.

Tolerance

Tolerance is defined as the margin providing for reasonable error in workmanship.

Limits

By limits is meant both tolerance and allowance; that is, the possible error in workmanship plus the amount decided upon in order to give the required fit to the work.

The Newall tables are the simplest and most compact, but it should be realised that the B.S.I., the A.S.A., and the I.S.A. have prepared similar but more extensive tables dealing with limits for cylindrical fits.

The "tolerances" for standard holes are in two grades, the selection of which is for the user's decision and dependent upon the quality of the work required.

Tables of Limits (Newall)

Tolerance in Standard Holes

	Nominal Diameters.	Up to $\frac{1}{2}$ In.	$\frac{9}{16}$ to 1 In.	$1\frac{1}{16}$ to 2 In.	$2\frac{1}{16}$ to 3 In.	$3\frac{1}{16}$ to 4 In.	$4\frac{1}{16}$ to 5 In.	$5\frac{1}{16}$ to 6 In.
Grade I	High limit .	+ ·00025	+ ·00050	+ ·00075	·00100	+ ·00100	+ ·00100	+ ·00150
	Low ,, .	− ·00025	− ·00025	− ·00025	− ·00050	− ·00050	− ·00050	− ·00050
	Tolerance .	·00050	·00075	·00100	·00150	·00150	·00150	·00200
Grade II	High limit .	+ ·00050	+ ·00075	+ ·00100	+ ·00125	·00150	+ ·00175	+ ·00200
	Low ,, .	− ·00050	− ·00050	− ·00050	− ·00075	− ·00075	− ·00075	− ·00100
	Tolerance .	·00100	·00125	·00150	·00200	·00225	·00250	+ ·00300

	Nominal Diameters.	$6\frac{1}{16}$ to 7 In.	$7\frac{1}{16}$ to 8 In.	$8\frac{1}{16}$ to 9 In.	$9\frac{1}{16}$ to 10 In.	$10\frac{1}{16}$ to 11 In.	$11\frac{1}{16}$ to 12 In.
Grade I	High limit .	+ ·00150	+ ·00175	+ ·00175	+ ·00175	+ ·00200	+ ·00200
	Low ,, .	− ·00075	− ·00075	− ·00100	− ·00100	− ·00100	− ·00100
	Tolerance .	·00225	·00250	·00275	·00275	·00300	·00300
Grade II	High limit .	+ ·00225	+ ·00225	+ ·00250	+ ·00250	+ ·00275	+ ·00275
	Low ,, .	− ·00100	− ·00125	− ·00125	− ·00125	− ·00125	− ·00150
	Tolerance .	·00325	·00350	·00375	·00375	·00400	·00425

The shafts made to the following table of force fits will require either hydraulic pressure to force them into the holes, or the holes to be expanded by heating so as to shrink them on to the shafts.

Force Fits

Nominal Diameters.	Up to $\frac{1}{2}$ In.	$\frac{9}{16}$ to 1 In.	$1\frac{1}{16}$ to 2 In.	$2\frac{1}{16}$ to 3 In.	$3\frac{1}{16}$ to 4 In.	$4\frac{1}{16}$ to 5 In.	$5\frac{1}{16}$ to 6 In.
High limit	+ ·00100	+ ·00200	+ ·00400	+ ·00600	+ ·00800	+ ·01000	+ ·01200
Low ,,	+ ·00050	+ ·00150	+ ·00300	+ ·00450	+ ·00600	+ ·00800	+ ·01000
Tolerance	·00050	·00050	·00100	·00150	·00200	·00200	·00200

Nominal Diameters.	$6\frac{1}{16}$ to 7 In.	$7\frac{1}{16}$ to 8 In.	$8\frac{1}{16}$ to 9 In.	$9\frac{1}{16}$ to 10 In.	$10\frac{1}{16}$ to 11 In.	$11\frac{1}{16}$ to 12 In.
High limit	+ ·014	·016	+ ·018	+ ·020	+ ·022	+ ·024
Low ,,	+ ·012	+ ·014	+ ·016	+ ·018	+ ·020	+ ·022
Tolerance	·002	·002	·002	·002	·002	·002

The table of driving fits will produce shafts that need to be driven into the holes.

Driving Fits

Nominal Diameters.	Up to $\frac{1}{2}$ In.	$\frac{9}{16}$ to 1 In.	$1\frac{1}{16}$ to 2 In.	$2\frac{1}{16}$ to 3 In.	$3\frac{1}{16}$ to 4 In.	$4\frac{1}{16}$ to 5 In.	$5\frac{1}{16}$ to 6 In.
High limit	+ ·00050	+ ·00100	+ ·00150	+ ·00250	+ ·00300	+ ·00350	+ ·00400
Low ,,	+ ·00025	+ ·00075	+ ·00100	+ ·00150	+ ·00200	+ ·00250	+ ·00300
Tolerance	·00025	·00025	·00050	·00100	·00100	·00100	·00100

Nominal Diameters.	$6\frac{1}{16}$ to 7 In.	$7\frac{1}{16}$ to 8 In.	$8\frac{1}{16}$ to 9 In.	$9\frac{1}{16}$ to 10 In.	$10\frac{1}{16}$ to 11 In.	$11\frac{1}{16}$ to 12 In.
High limit	+ ·00450	+ ·00500	+ ·00550	+ ·00600	+ ·00650	+ ·00700
Low ,,	+ ·00300	+ ·00350	+ ·00400	+ ·00450	+ ·00450	+ ·00500
Tolerance	·00150	·00150	·00150	·00150	·00200	·00200

Shafts made to push fit sizes can be pushed into holes, but will not be sufficiently free to rotate without seizing.

Push Fits

Nominal Diameters.	Up to $\frac{1}{2}$ In.	$\frac{9}{16}$ to 1 In.	$1\frac{1}{16}$ to 2 In.	$2\frac{1}{16}$ to 3 In.	$3\frac{1}{16}$ to 4 In.	$4\frac{1}{16}$ to 5 In.	$5\frac{1}{16}$ to 6 In.
High limit	- ·00025	- ·00025	- ·00025	- ·0005	- ·0005	- ·0005	- ·0005
Low ,,	- ·00075	- ·00075	- ·00075	- ·0010	- ·0010	- ·0010	- ·0010
Tolerance	·0005	·0005	·0005	·0005	·0005	·0005	·0005

Nominal Diameters.	$6\frac{1}{16}$ to 7 In.	$7\frac{1}{16}$ to 8 In.	$8\frac{1}{16}$ to 9 In.	$9\frac{1}{16}$ to 10 In.	$10\frac{1}{16}$ to 11 In.	$11\frac{1}{16}$ to 12 In.
High limit	- ·00050	- ·00050	- ·00050	- ·00075	- ·00075	- ·00075
Low ,,	- ·00125	- ·00150	- ·00150	- ·00200	- ·00200	- ·00200
Tolerance	·00075	·00100	·00100	·00125	·00125	·00125

A running fit is where a shaft is of such a diameter that it will revolve quite freely in the hole which it fits, and also leave a space for a film of oil. In the following table, Class X is intended for engine and other work where easy fits are wanted; Class Y for high speeds and good average machine work; Class Z for fine tool work.

RUNNING FITS

	Nominal Diameters.	Up to ½ In.	$\frac{9}{16}$ to 1 In.	$1\frac{1}{16}$ to 2 In.	$2\frac{1}{16}$ to 3 In.	$3\frac{1}{16}$ to 4 In.	$4\frac{1}{16}$ to 5 In.	$5\frac{1}{16}$ to 6 In.
Class X -	High limit .	– ·00100	– ·00125	– ·00175	– ·00200	– ·00250	– ·00300	– ·00350
	Low " .	– ·00200	– ·00275	– ·00350	– ·00425	– ·00500	– ·00575	– ·00650
	Tolerance .	·00100	·00150	·00175	·00225	·00250	·00275	·00300
Class Y -	High limit .	– ·00075	– ·00100	– ·00125	– ·00150	– ·00200	– ·00225	– ·00250
	Low " .	– ·00125	– ·00200	– ·00250	– ·0 300	– ·00350	– ·00400	– ·00450
	Tolerance .	·00050	·00100	·00125	·00150	·00150	·00175	·00200
Class Z -	High limit .	– ·00050	– ·00075	– ·00075	– ·00100	– ·00100	– ·00125	– ·00125
	Low " .	– ·00075	– ·00125	– ·00150	– ·00200	– ·00225	– ·00250	– ·00275
	Tolerance .	·00025	·00050	·00075	·00100	·00125	·00250	·00150

	Nominal Diameters.	$6\frac{1}{16}$ to 7 In.	$7\frac{1}{16}$ to 8 In.	$8\frac{1}{16}$ to 9 In.	$9\frac{1}{16}$ to 10 In.	$10\frac{1}{16}$ to 11 In.	$11\frac{1}{16}$ to 12 In.
Class X -	High limit .	– ·00350	– ·00350	– ·00375	– ·00400	– ·00400	– ·00425
	Low " .	– ·00675	– ·00700	– ·00750	– ·00800	– ·00825	– ·00850
	Tolerance .	·00325	·00350	·00375	·00400	·00425	·00425
Class Y -	High limit .	– ·00275	– ·00275	– ·00300	– ·00325	– ·00325	– ·00350
	Low " .	– ·00475	– ·00500	– ·00550	– ·00575	– ·00600	– ·00625
	Tolerance .	·00200	·00225	·00250	·00250	·00275	·00275
Class Z -	High limit .	– ·00125	– ·00150	– ·00150	– ·00150	– ·00175	– ·00 75
	Low " .	– ·00275	– ·00300	– ·00300	– ·00325	– ·00350	– ·00350
	Tolerance .	·00150	·00150	·00150	·00175	·00175	·00175

Johansson Block Gauges

The standard block gauges manufactured by Messrs C. E. Johansson, of Sweden, are probably the most accurate standards made. A set of these gauges consists of eighty-one pieces, and by using these separately or combined together over 80,000 different sizes can be obtained, any of such sizes being accurate to within

0.00004 of an inch at the standard temperature of 68° F. or 20° C.

The set of gauges is divided into four series as follows :—

1st series	0.1001	to 0.1009	by 0.0001	in.
2nd „	0.101	to 0.149	by 0.001	„
3rd „	0.050	to 0.950	by 0.05	„
4th „	1, 2, 3, and 4 in.			

From the above it will be seen that the gauges in the first series will divide up the space between those of the second series, while the third and fourth series can be divided up by the first and second series; or, in other words, any size can be obtained from 0.2000 in. up to 10 in., rising by 0.0001 in.

The illustration, Fig. 56, will show how very accurate these gauges are; here two similar length gauges are wrung

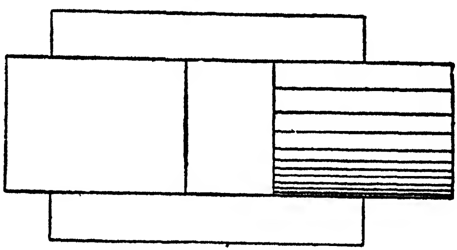


FIG. 56.—Standard Gauges.

to the surface of another gauge so as to adhere. On the opposite surfaces of the two similar length gauges a combination of eleven gauges are wrung. If there was the slightest difference in the size of the combination and the single gauge, it would be impossible to make the whole of the gauges adhere together.

In order to use the block gauges for internal and external measurements, points as shown in Fig. 57 have been

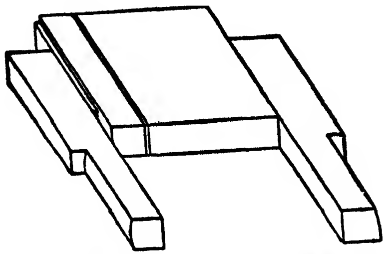


FIG. 57.—Block Gauges for External Measurements.

designed. These points are double the length of the gauges, and have one surface lapped to the same degree of accuracy and planeness as the gauges. By wringing them over the end surfaces of a combination or a single gauge they adhere and form an exact "snap" gauge. For half the length of the opposite sides they are rounded to a certain radius, and by adding the thickness of these points where radiused to the size of the gauge or gauges between the points, an accurate "plug" gauge is made.

By this method any or all of the sizes are obtainable from the set of blocks, and an accurate "plug" or "snap" gauge can be made up in a few seconds as desired.

Application

For adjusting a snap gauge to an exact size, a check gauge of this size is required, and to adjust a limit snap gauge, two check gauges are wanted, and it is evident that in a factory where a great variation of sizes is used, the number of check gauges would become great if one gauge

for every size had to be provided. A complete set of gauges as previously described allows for all variations that may be required. Even when the snap gauges are being lapped to their exact size, a combination of gauges as shown in Fig. 58 is of great value because it enables the operator to follow gradually, by ten-thousandths of an inch, the lapping process or "feeling his way" to the size required, and thus ascertaining that not too much material is lapped off. Therefore, a snap gauge of say 1" + .001 final size can be milled to 1" - .001; after it has been hardened it could be ground to within one-thousandth, and when being lapped, the size can be verified gradually by ten-thousandths of an inch, *i.e.*, 1" + .0002, 1" + .0003 + .0008 + .0009, etc., until the right size, 1" + .001, is arrived at.

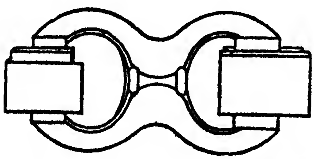


FIG. 58.—Use of Block Gauges.

Adjustable Caliper Gauges

The illustration in Fig. 59 gives the class of fits which are of importance in the construction of a particular type of vertical drilling machine, and also the limit caliper gauges necessary for their measurement.

As will be seen from the illustration, the bores of one diameter are constant, and the diameter of the shaft differs so that the variation in measurement is confined to the outside caliper gauges. Without diminishing in any way the quality of a job thus produced, a very important economy is effected; in fact, as only one normal or standard bore is used, one set of boring tools (drill reamer and plug gauge) suffices for one diameter

of hole, while formerly a set of tools was necessary for each fit

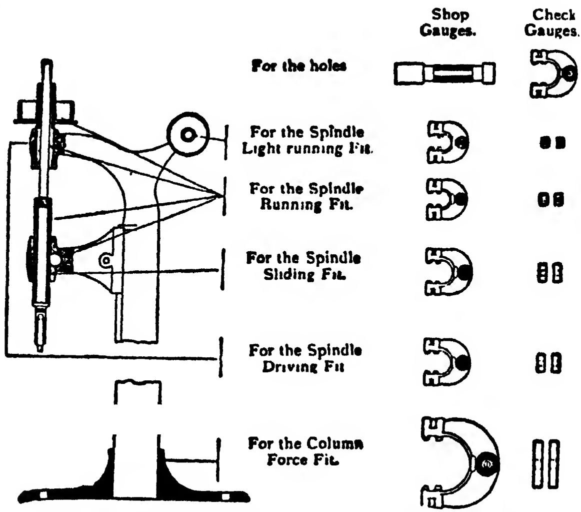


FIG. 59.—Gauge System Applied to Drilling Machine.

In the table of limits, the various limits of the different fits for "standard" bore are shown. These limits are used in general practice, and are given as an example, and the caliper gauges are, if necessary, specially adjusted to these limits.

Standard Caliper Gauges

A type of standard gauge used for both internal and external measurements is shown in Fig. 60. These gauges are made from steel, hardened, ground, and lapped to within the limits desired. This form of gauge

TABLE OF LIMITS FOR STANDARD HOLES

Diameter.	Limit Plug Gauges.		Limit Caliper Gauges.									
			Light Running Fit.		Running Fit.		Sliding Fit.		Driving Fit.		Force Fit.	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.
[illegible] – [illegible]	−0·00019	+0·00019	−0·00118	−0·00039	−0·00059	−0·00019	−0·00027	−0·00011	−0·00011	+0·00023	+0·00059	+0·00098
[illegible] – [illegible]	−0·00039	+0·00039	−0·00157	−0·00078	−0·00098	−0·00039	−0·00039	−0·00019	−0·00019	+0·00039	+0·00098	+0·00157
[illegible] – [illegible]	−0·00059	+0·00039	−0·00216	−0·00118	−0·00118	−0·00059	−0·00059	−0·00023	−0·00019	+0·00035	+0·00118	+0·00196
[illegible] – 1[illegible]	−0·00059	+0·00059	−0·00275	−0·00157	−0·00137	−0·00078	−0·00078	−0·00027	−0·00023	+0·00035	+0·00137	+0·00255
1[illegible] – 1[illegible]	−0·00078	+0·00059	−0·00354	−0·00196	−0·00177	−0·00098	−0·00098	−0·00031	−0·00023	+0·00031	+0·00157	+0·00314
1[illegible] – 2[illegible]	−0·00078	+0·00078	−0·00413	−0·00236	−0·00196	−0·00118	−0·00118	−0·00035	−0·00027	+0·00027	+0·00196	+0·00393
3 – 4[illegible]	−0·00098	+0·00078	−0·00472	−0·00275	−0·00236	−0·00137	−0·00135	−0·00039	−0·00035	+0·00023	+0·00236	+0·00472
4[illegible] – 6[illegible]	−0·00118	+0·00098	−0·00551	−0·00314	−0·00295	−0·00157	−0·00177	−0·00055	−0·00039	+0·00019	+0·00314	+0·00590
6[illegible] – 10[illegible]	−0·00177	+0·00118	−0·00629	−0·00354	−0·00354	−0·00196	−0·00196	−0·00070	−0·00047	+0·00015	+0·00393	+0·00787

is to be preferred to the plug and ring gauge on account of lightness and general adaptability, and they give a reliable and convenient method of obtaining standard sizes for holes and shafts, and are intended for everyday use in the machine shop.

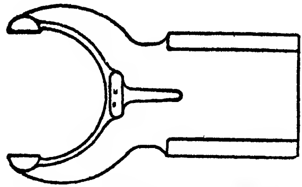


FIG. 60.—Standard Internal and External Gauge.

Standard Plug and Ring Gauge

The plug and ring type of standard gauge, shown in Fig. 61, are mainly used as standard gauges. They are

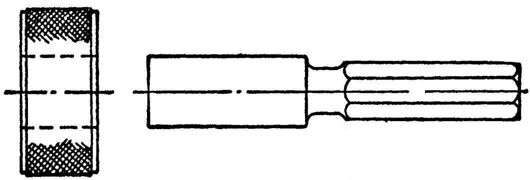


FIG. 61.—Standard Cylindrical Gauges.

usually made from steel, and are hardened, ground, and lapped to the sizes required.

Single Ended Caliper Gauges

The single ended type of standard caliper gauge is shown in Fig. 62; this type is generally used for sizes of 3 in. and over. They are of great use as standards for setting measuring rods, and in certain cases as working gauges, especially where great accuracy is required. The

anvils are made of hardened steel, and when worn can be renewed at comparatively low cost.

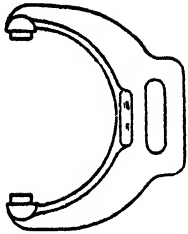


FIG. 62.—Standard Single Ended Limit Gauge.

Single Ended Limit Gauges

The adjustable type of single ended caliper gauge is shown in Fig. 63. The measuring anvils or points of this gauge do not rotate either in or out, and being made a sliding fit, their movement can be actuated by a small independent screw placed behind them. The points are furnished with a binding strip, on which the conical part of a binding screw operates in such a manner that neither

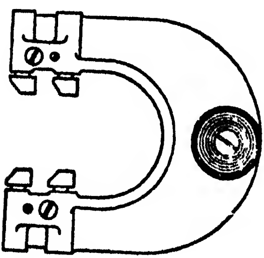


FIG. 63.
Single Ended Limit Gauge.

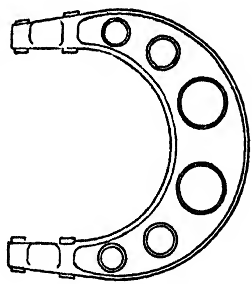


FIG. 64.
Fixed Point Limit Gauge.

of them is moved by the regulating screw, the latter only effecting the movement of its respective point. This construction guarantees the perfect and constant parallelism of all the measuring surface notwithstanding any change of anvil position.

The Newall gauge with fixed points is shown in Fig. 64. It carries two pairs of anvils, the front pair being the "go" and the back the "not go" points. The anvils are ground and lapped to the degree of accuracy required in order to give the desired tolerance.

The form of gauge shown in Fig. 69 has the advantage over cylindrical plug gauges, inasmuch as it can be easily inserted in a hole, and has less tendency to bind. They are exceedingly useful when starting a boring cut, as they can be inserted in a very small length of bore, and if this is not quite the full diameter, the difference can easily be estimated by the feel of the ball. In addition, the gauges are very quickly tried in holes, because they do not bind, and because a kind of a wedge action is set up.

In many shops this type of gauge is taking the place of the ordinary plug, though of course they cannot displace them for all purposes.

Double Ended Limit Gauges

Two different types of double ended external limit gauges are shown in Fig. 65 and Fig. 66. These are used in the workshop, not only for finishing operations, but also

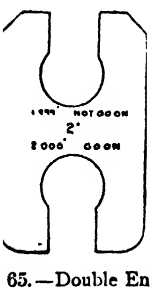


Fig. 65.—Double Ended Limit Gauge.

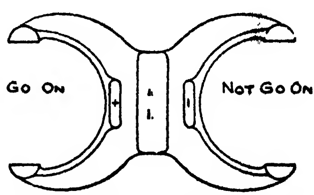


Fig. 66.—External Limit Gauge.

for roughing down. When used for the latter purpose, the same amount of stock is left on each job, thus enabling the machinist finishing the work to arrange his tools in a more satisfactory manner than he would be able to do if the work had been left in a variety of sizes. It is important that the degree of tolerance should be stamped on all gauges of this type, and also that some difference, either in shape or making, should be made of the " go in " or " not go in " ends.

Internal Limit Gauges

Cylindrical limit gauges, as shown in Fig. 67, are usually

FIG. 67.
Plain "Go" and "No Go" Plug Gauge.
(By courtesy of Messrs Newall Engineering Co. Ltd., Peterborough.)

made so that the longest end is the maximum limit below standard, or " go in " size, and the shortest end the maximum above standard, or "not go in" size. It will be seen that if one end of the gauge is made 1.999 and the other 2.001, not shown in the illustration, then the tolerance will be .002, and the maximum amount the hole can depart from the nominal size will be .001, or one-thousandth of an inch above or below standard.

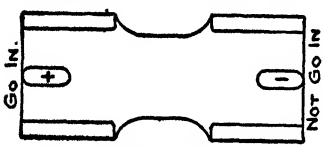


FIG. 68.
Internal Limit Gauge.

A much used type of internal limit gauge is shown in Fig. 68. This is a simple and useful class of gauge. The lettering panels and the sides of the jaws are on the same

plane, and may be finished by a single grinding. Four classes of this type of gauge are in use :—

1. Plain gauge; single dimensions both ends.

2. Standard size one end; other end having "go" and "not go" sizes.

3. Limit gauge; high limit one end, low limit other end.

4. Gauge of the "go in" and "not go in" class at either end, two combinations.

Ball Gauge

These gauges are intended for gauging and reference purposes. They are made of special grade steel, and are

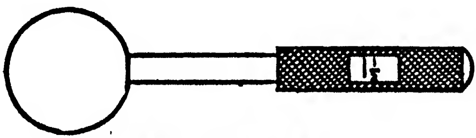


FIG. 69.—Standard Ball Gauge.

machined to within the limit of .0001 of an inch. Fig. 69 shows the form the gauge takes.

Standard Screwed Plug Gauges

The standard screwed plug gauges are generally as shown at Figs. 70 to 75. The gauges are of the built-up type with the gauging members fitting by means of a taper shank into a standard handle. Each gauging portion is of steel, hardened, stabilised, ground, and then lapped to size. The six types should cover both the workshop and inspection requirements and the caption given under each illustration indicates the function of the particular gauge.

FIG. 70.—Single-ended "Go" Screw Gauge. Style Normal.

FIG. 71.—"No Go" Single-ended Screw Gauge. Style D.

FIG. 72.—Double-ended Screw Gauge with "Go" and "No Go" Screwed Ends. Style E.

FIG. 73.—"Go" Screwed, No. 60 Plain End Plug Gauge. Style F.

FIG. 74.—Screwed "Go" Plug Gauge with "Go" Screwed and Plain Ends. Style G.

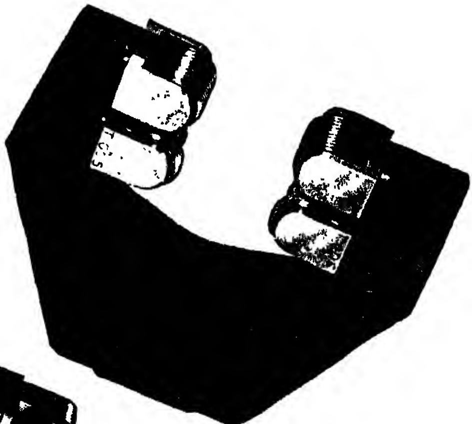
FIG. 75.—"No Go" Screwed Plug Gauge. Style H.

(All by courtesy of Messrs Newall Engineering Co. Ltd., Peterborough.)

Adjustable Caliper Screw Gauge

The adjustable type of caliper gauge as used for checking the dimensions of an external thread are shown at Figs. 76 and 77. With this class of gauge the setting is done in

FIG. 76.



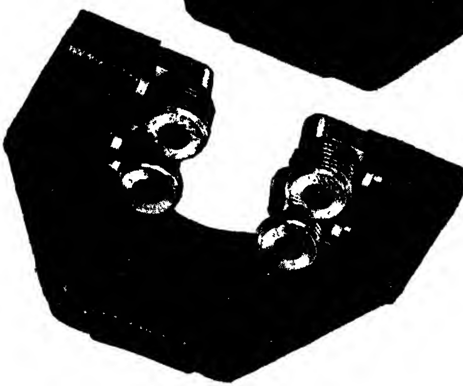


FIG. 77.

conjunction with a master screwed plug gauge similar to that shown at Fig. 72. As each gauge has a set of "Go" and "No Go" rollers or anvils, one handling of the component permits effective control of the thread thickness.

CHAPTER IV

COMMON WORKSHOP TOOLS

WITH the growth of industry, specialisation has led to the manufacture on a large scale of a wide range of small tools and measuring equipment as used by the craftsman in the engineering shop. Here, as in so many other fields, the transfer from small-scale production has resulted in an improved version of the tool or instrument, a number of which are shown and discussed below.

Calipers

The use of all forms of calipers in the modern workshop is rapidly giving way to the more accurate micrometer and the limit gauge.

If approximate measurements only are required, calipers will be found very useful tools. They are constructed in a very large variety of forms, and, when in the hands of a skilled workman, they can be used to very fine limits. The difficulty with calipers is, that when they are adjusted very accurately no reading is given, and it is difficult to obtain from a rule a smaller linear measurement than one-hundredth of an inch.

Accurate calipering with ordinary inside and outside calipers is a question of "feel"; that is, it is necessary for the user to know and judge how hard the contact points touch the work, and how much spring there is in the caliper legs. In Fig. 78 it will be seen that very little

bearing surface can be given to the contact points of the caliper on account of the different angles formed by the legs in various positions. To transfer any particular size

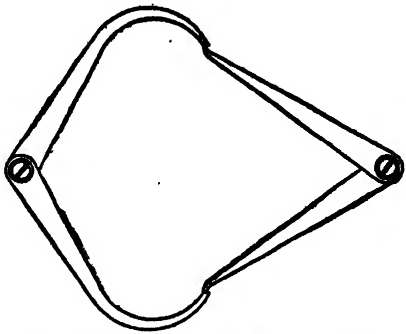


FIG. 78.—Inside and Outside Calipers.

from inside to outside calipers, or vice versa, is an extremely difficult job, requiring considerable practice, much patience, and also allowing a possibility of error.

A very good type of outside caliper is illustrated in Fig. 79. The legs are adjusted by means of a knurled nut, and when this nut is provided with a spring chuck a considerable saving of time is obtained, as the thread of the nut engages the screw at the slightest pressure, and when the pressure is withdrawn it slides freely over the outside of the screw.

Inside Calipers

A good type of inside caliper is shown in Fig. 80. The working of this is similar to the previous example. When using the inside caliper for calipering the diameter of a hole, one of the legs is kept stationary, and with the point of the

other leg two small arcs should be made, first in a line with the hole and then at right angles to the hole. This method

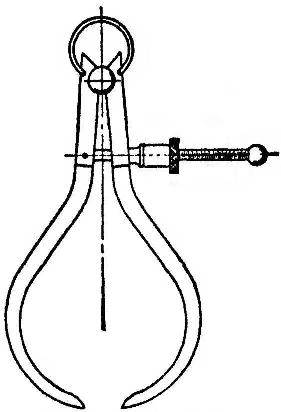


FIG. 79.—Outside Calipers.

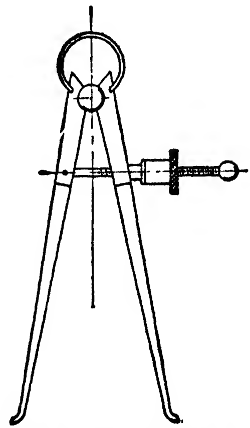


FIG. 80.—Inside Calipers.

of using will allow of the caliper being adjusted to the maximum size; for finer adjustments the caliper can then be moved up and down the hole.

The best method for setting the inside caliper to a given size is shown in Fig. 81. Here a scale is placed against the edge of a piece of metal, the caliper being laid on the scale with one leg against

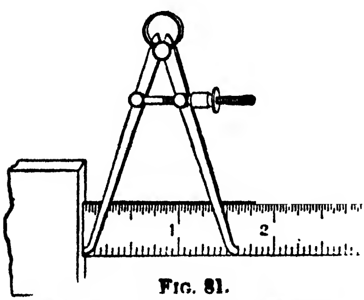


FIG. 81.
Method of Setting Inside Calipers.

the edge of the metal, the other leg being adjusted to the size required.

Transfer Calipers

Transfer calipers for inside and outside work are shown in Figs. 82 and 83. These tools may be used for taking thicknesses or diameters inside cavities, or over projecting flanges, and for work of a similar description, of which two examples are given. The caliper is used by first loosening the nut binding one arm to the auxiliary leaf and swinging it out or in (while the nut is locked) to clear the obstruction, and then moving it back against the stop, where it will show the size required.

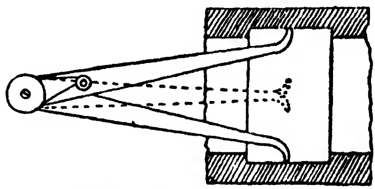


FIG. 82.—Inside Transfer Calipers.

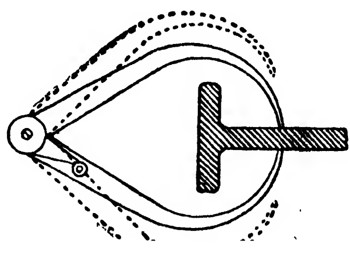


FIG. 83.—Outside Transfer Calipers.

Thread Calipers

A useful type of caliper is shown in Fig. 84. This is called a "hermaphrodite" or "jenny" caliper, and will be

found particularly useful in many marking out operations where great accuracy is not required.

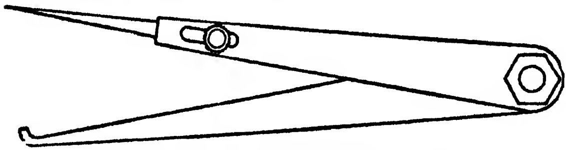


FIG. 84.—Hermaphrodite Caliper or "Jenny."

For special work, such as measuring the outside diameter of a screwed thread, or the core diameter of a screw, special

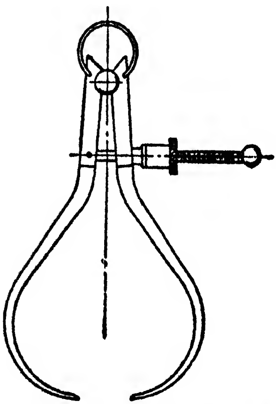


FIG. 85.—Thread Calipers, for Outside Measurement.

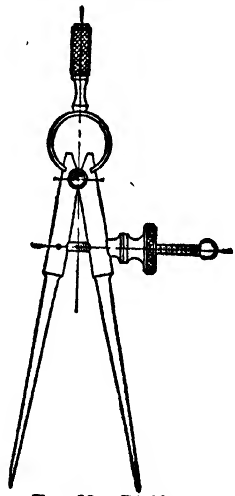


FIG. 86.—Dividers.

calipers with suitable shaped ends are used; these may be broad, as in Fig. 85, or very thin, in order to go right to the bottom of the thread space.

Dividers

The best and most useful form of divider is shown in Fig. 86. The points are hardened and tempered to prevent wear, and the tool is used for such purposes as scribing arcs and circles, and for general marking out purposes.

Scribers

Two forms of scribers are shown in Fig. 87. They are made from carbon steel with the points hardened, and they

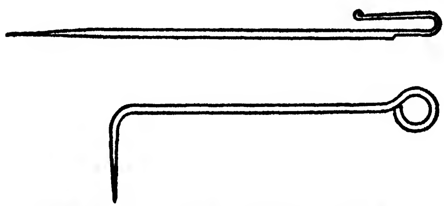


Fig. 87.—Bent and Straight Scribers.

are used for scratching or marking the surface of metal. The bent scriber can often be used in places where it is impossible to manipulate the straight scriber.

When it is necessary to mark the faces of finished work, a scriber made from brass, with a pointed end, can be used without scratching or spoiling the surface of the work.

Straight Edges

Straight edges may take the form of a simple 6-in. or 12-in. rule with its edge accurately ground, or the more elaborate special straight edge shown in Fig. 88. In either case they are used for testing the accuracy of surfaces for planeness.

Taking a cross-section through small straight edge, the finish should be such as to produce a small radius for the full effective length of the instrument as both a flat surface or an exceedingly sharp knife edge are undesirable.

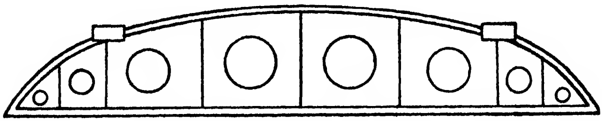


FIG. 88.—Large Straight Edge.

Try Squares

The try square shown in Fig. 89 is used to test the accuracy of two surfaces at right angles to each other. The

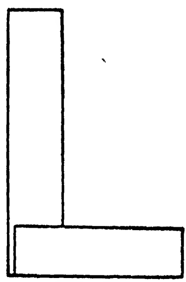


FIG. 89.
Try Square.

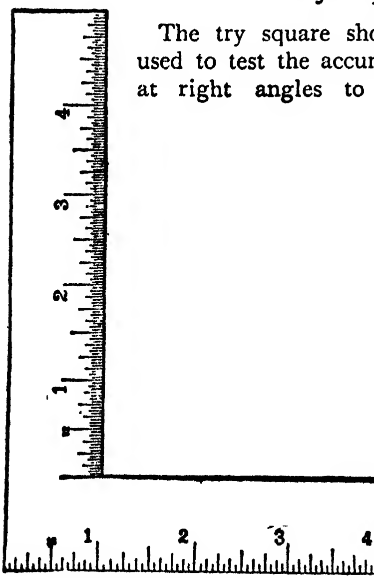


FIG. 90.—Flat Graduated Engineer's Try Square.

best forms are made from one piece of steel machined to shape, then hardened, and afterwards accurately ground to size.

Another type of square is shown in Fig. 90. This is made from one piece of metal, and is of the same thickness throughout. It is an extremely useful tool for use on the marking-off table, being graduated on all its edges.

Combination Tools

The combination set shown in Fig. 91 consists of a bevel protractor, square, and centre square. This makes a variety

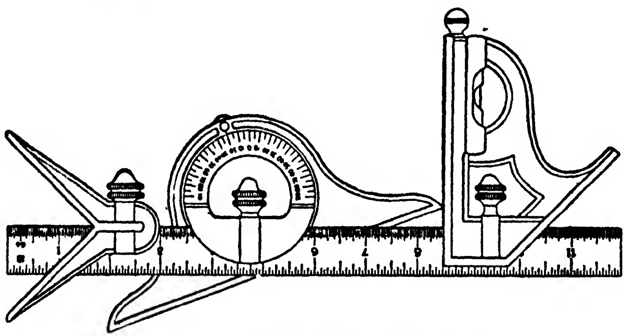


FIG. 91.—Combination Set of Squares.

of operations possible with one tool, and for setting out and testing work it is a most reliable and useful tool.

Centre or Dot Punches

The ordinary dot punch generally consists of a piece of hexagonal, octagonal, or round section steel, shaped as shown in Fig. 92, with the point ground to an angle of 60°, and afterwards hardened. This tool is used for dotting the

lines on work which have been marked out. The dots made by the punch should be light, about $\frac{3}{8}$ in. apart, and exactly on the line, so that when the machining is finished half the dot will be left to show on the work.

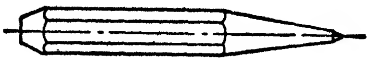


FIG. 92.—Centre Punch.

To make the spacing of the dots easier than is possible with the ordinary punch, the special spacing punch shown in Fig. 93 is often used. This punch, in addition to having the spacing attachment, is automatic, the point of the punch being actuated by means of a strong spring; thus with this punch it is possible to accurately space all the dots, and at the same time rely on the dots being all one size.

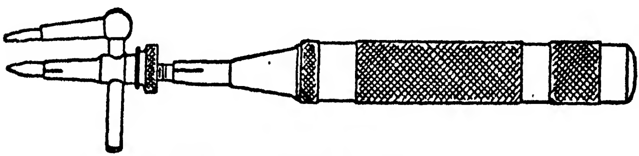


FIG. 93.—Automatic Spacing Centre Punch.

Scribing Block

The scribing block or surface gauge is made in a variety of forms, and often consists of a steel pillar fitted into a cast-iron block or base, and provided with various adjustments for altering the height of the scriber point. It is used in conjunction with a surface plate or marking-off table, for scribing centre and other lines on work which have to be parallel to a common base.

In using the scribing block, the point of the scriber should not be allowed to project further than is absolutely necessary, and when the lines are being drawn the scriber point should follow the pillar, and should not be at right

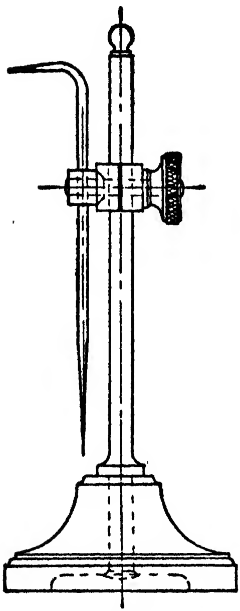


FIG. 94.—Scribing Block.

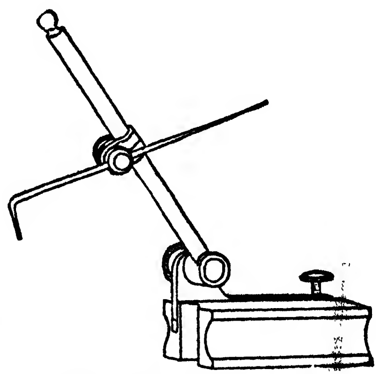


FIG. 95.--Universal Surface Gauge.

angles or in advance of the column. A simple form of this useful tool is shown in Fig. 94.

What is known as a universal scribing block is illustrated in Fig. 95. This tool can be used for a variety of purposes, some of which are shown in Fig. 96.

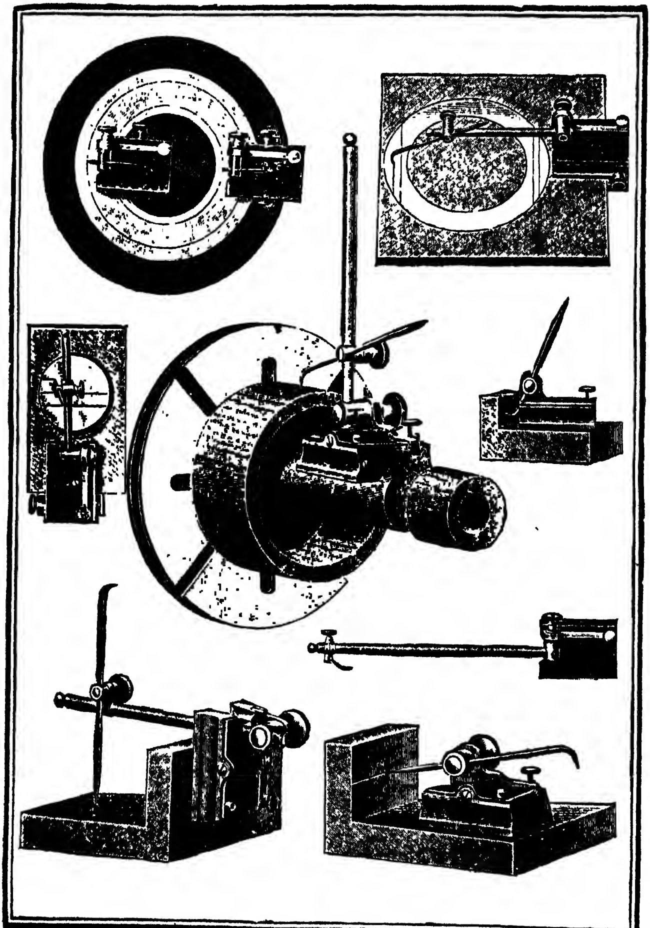


FIG. 96.—Methods of Using the Universal Scribing Block.

Combination Bevel Gauge

An extremely useful and simple type of combination gauge is shown in Fig. 97. The bevel has a stud riveted in the straight edge or stock, on which a split blade is hinged so as to swing over the stock; the latter can be clamped at any desired angle. The slotted auxiliary

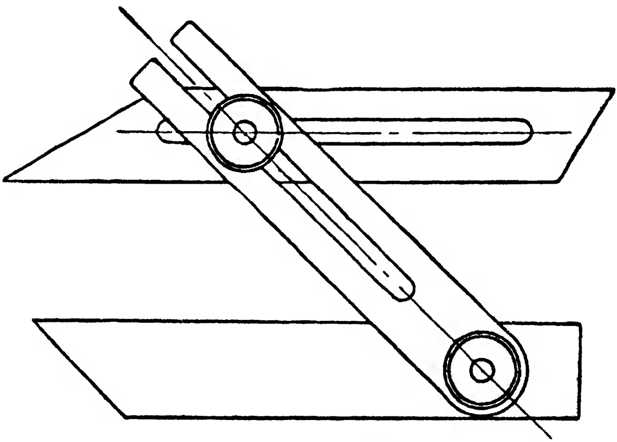


FIG. 97.—Combination Bevel Gauge.

blade with the clamp bolt may be slipped on the slotted blade and can also be clamped to any angle; it can be used in combination with the other two blades for laying out angles, and when so combined will lie flat on the work.

The various uses to which this tool can be put are clearly shown in Fig. 98; the illustrations will be found self-explanatory.

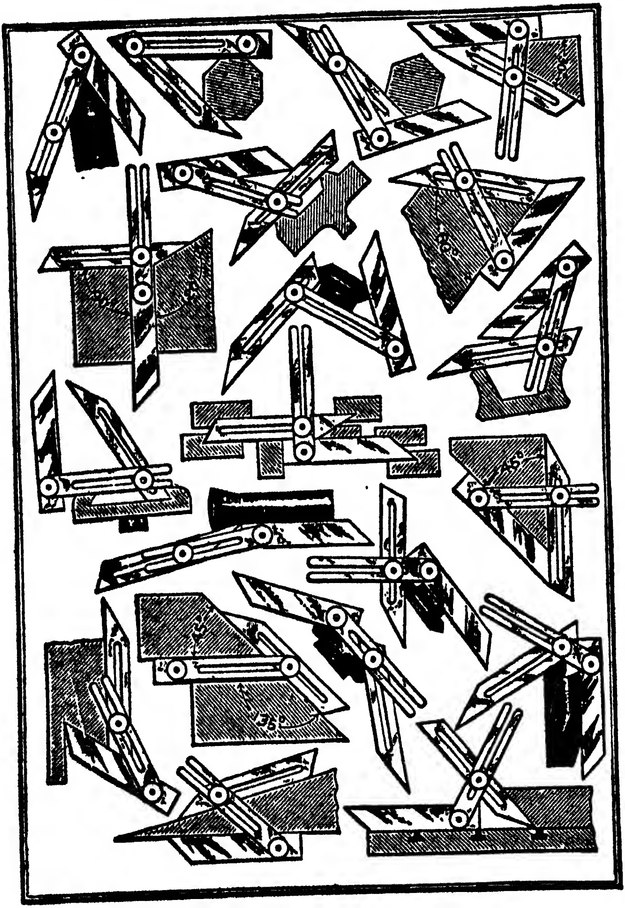


FIG. 98.—Method of Using Combination Bevel Gauge.

A simple type of bevel gauge is shown in Fig. 99. As in the previous example, it can be used to transfer angles from

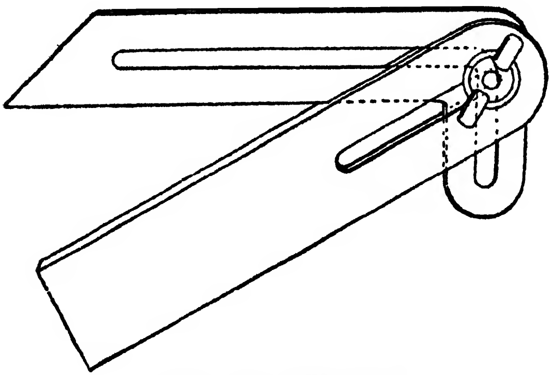


Fig. 99.—Simple Bevel Gauge.

one piece of work to another, or the gauge can be set by means of a bevel protractor or a sine-bar.

Trammels

The trammel is used for the same purpose as the divider, that is, for marking out circles, arcs, and work of a similar nature. This beam of the tool, shown in Fig. 100, is $\frac{5}{16}$ in. round, with one side flattened. It is made up of two or more sections, as necessary, by means of a connecting coupling. Fine adjustments can be obtained by means of the knurled nut and screw.

Screw Pitch Gauge

The type of screw pitch gauge, shown in Fig. 101, will measure the pitch of nuts and threads in twenty-two

different pitches. The smaller pitches are on narrow blades when of twenty threads per inch and less.

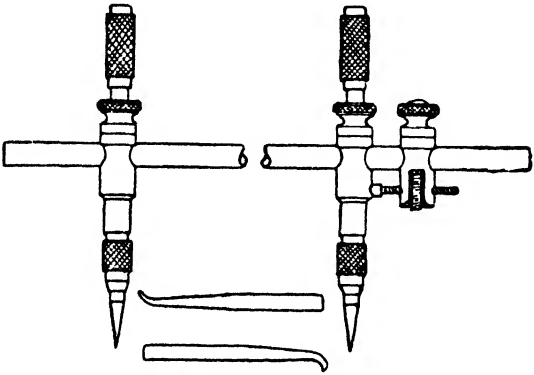


FIG. 100.—Adjustable Trammels.

Gauges are constructed to the Whitworth standard, United States standard thread, Système International, and the fine V thread.

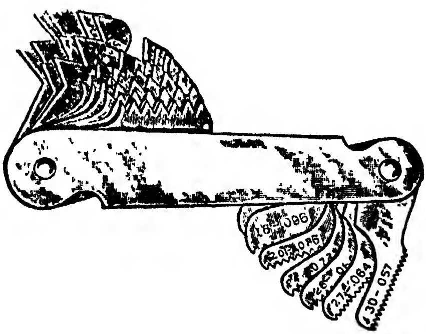


FIG. 101.—Screw Pitch Gauge.

An improvement in these screw pitch gauges consists in stamping on each leaf decimals showing the double depth of thread; this, of course, equals the depths of threads on the two sides of the screw, and helps the mechanic to determine the size of drill to give the correct size for tapping purposes. To obtain this size it is necessary to caliper with a micrometer over the threads of the screw, and from the size obtained in thousandths of an inch deduct the decimals given on the pitch gauge leaf. The result will show in thousandths the size of drill necessary to give a full thread.

Key-Seat Rules

A key-seat rule or box-square is shown in Fig. 102. This tool is used for marking out key-seats, mortises, etc., on

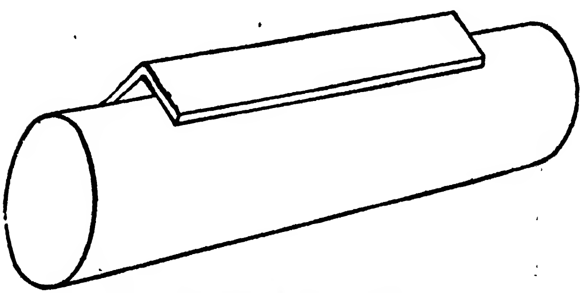


FIG. 102.—Key-Seat Rule or Box Square.

round shafts; they can be frequently used when it is impossible or inconvenient to place the work on vee blocks and use the surface gauge.

An attachment for fitting to the ordinary steel rule or

straight edge is shown in Fig. 103; this answers the same purpose as the regular key-seat rule made from the solid.

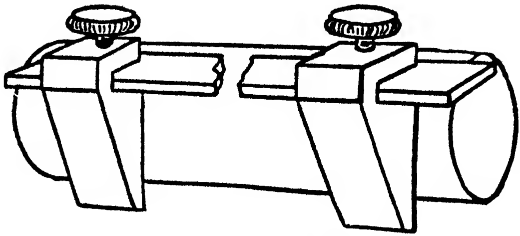


FIG. 103.—Key-Seat Attachment.

Taper Gauge

The taper gauge shown in Fig. 104 can be used for measuring approximately the width of slots, sizes of nuts, and other similar jobs.

The thin leaves of the gauge are tapering, the width varying $\frac{1}{64}$ in. to every $\frac{1}{4}$ in. of their length. They are graduated in $\frac{1}{4}$ in., and figured to read in fractions of an inch from $\frac{1}{16}$ to $1\frac{1}{16}$ in.

Radius Gauge

The radius gauge shown in Fig. 105 consists of a number of steel gauges stamped to indicate radii by sixty-fourths of an inch from $\frac{1}{16}$ in. to $\frac{1}{4}$ in., and from $\frac{1}{8}$ in. to $\frac{1}{2}$ in. by thirty-seconds. This tool will be found useful for measuring and checking fillets and radii.

Several sizes are made in the English and metric standard, but where special radii or fillets have to be

reproduced, special gauges can be made to conform with the shape.

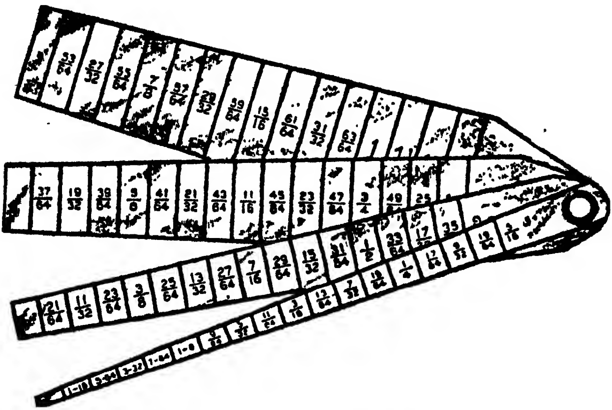


FIG. 104.—Taper Thickness Gauge.

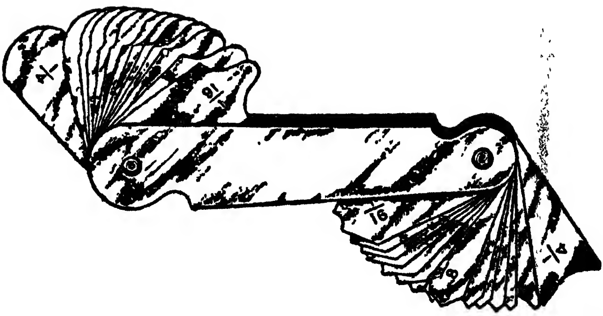


FIG. 105.—Fillet and Radius Gauge

Spirit Level

The spirit level is needed for erecting work, and also on the marking-off table. The type shown in Fig. 106 is

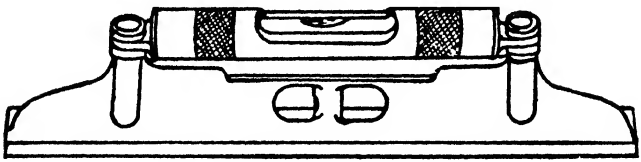


FIG. 106.—Adjustable Spirit Level.

provided with a double plumb or vial, the top one of which is adjustable. A spirit level fitted with a plumb at right angles to the longitudinal plumb will be found particularly useful, as it can be used to test work vertically as well as horizontally.

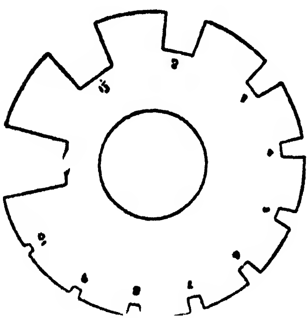


FIG. 107.—Acme Thread Gauge.

Acme Thread Gauge

The gauge shown in Fig. 107 is used as a standard gauge to which screw cutting tools can be ground in order to cut threads of a standard and uniform angle. The "acme" thread has the same depth as a square thread, but is considerably stronger. The sides are at an inclination of $14\frac{1}{2}°$, or a $29°$ included angle, which angle is now generally adopted for worm threads.

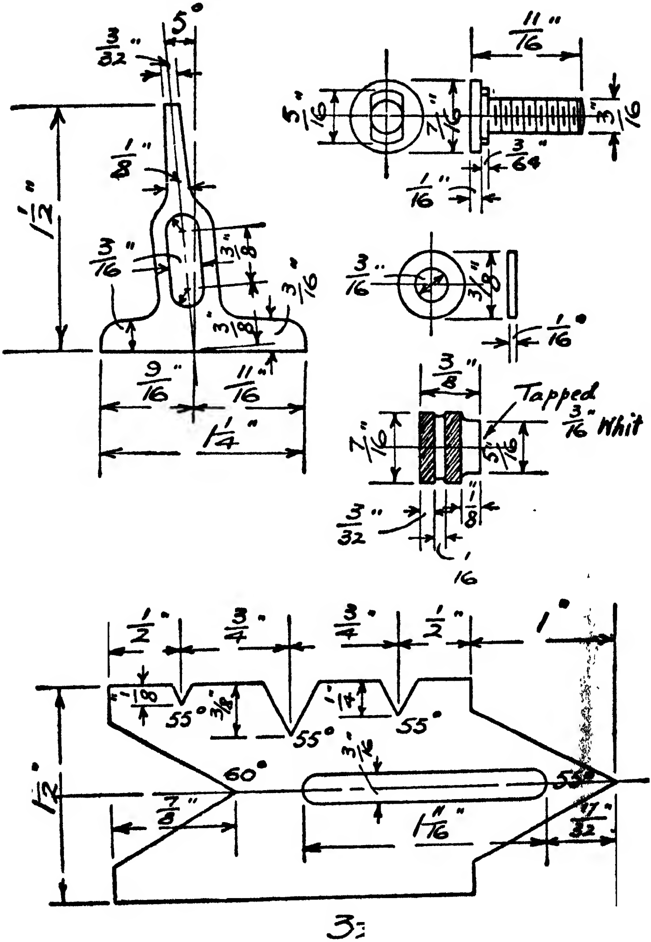


Fig. 108.—Details of Screw Cutting Gauge.

The parts of the 29° thread are obtained thus —

Width of point of tool for screw or tap thread =

$$\frac{\cdot 3707}{\text{Number of threads per inch}} - \cdot 0052.$$

Width of screw or nut thread $= \dfrac{\cdot 3707}{\text{Number of threads per inch}}$.

Diameter of tap = Diameter of screw + ·020.

Diameter of tap or screw at root =

$$\text{Diameter of screw} - \left(\frac{1}{\text{Number of linear threads per inch}}\right) + \cdot 020.$$

Depth of thread $= \dfrac{1}{2 \times \text{Number of threads per inch}} + \cdot 010.$

Screw Cutting Gauge

A very useful form of screw cutting gauge is shown in detail in Fig. 108. This tool is used for testing and setting up tools for cutting vee threads. It will be found to form a good exercise in fitting and turning, and for that reason the details are given in full.

CHAPTER V

BENCH WORK

Bench Vice. — The best type of vice for general engineering work is that provided with parallel jaws, as shown in Fig. 109. This class of vice is sometimes

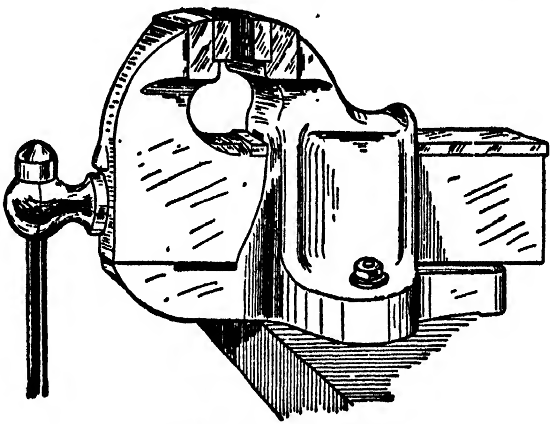


FIG. 109.—Parallel Bench Vice.

arranged so that the jaw attached to the body of the vice can be swivelled, and thus be made to grip tapered work.

In fixing the vice to the bench, it should be bedded down and held with bolts passing through the bench planks, and the jaws arranged to be overhanging the edge of the bench at a distance of about 40 in. above floor level. In each instance the working height will be arranged by either packing blocks or a stage to suit the man working at the vice.

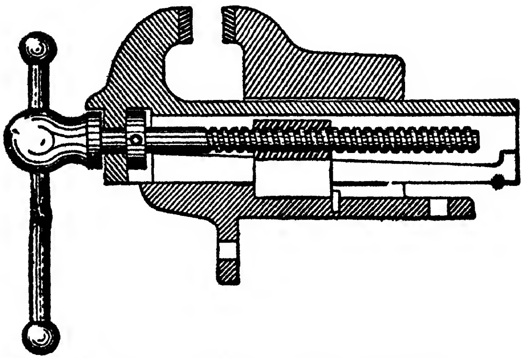


FIG. 110.—Section through Bench Vice.

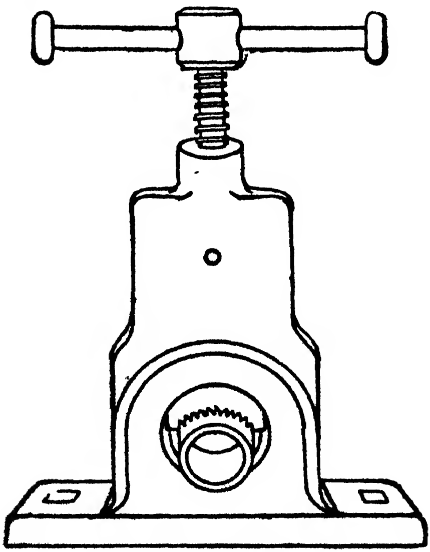


FIG. 111.—Pipe Vice.

A section through a parallel jaw vice is shown in Fig. 110. The inner faces of the jaws have serrated hardened steel strips secured to them.

Pipe Vice.—A special type of vice is used for holding round section metal and tubes, which generally takes the form of the one shown in Fig. 111. In this case the screw is vertical, and the movable jaw works vertically.

Hand Vices.—The hand vice is made in various patterns and sizes, and is used for gripping objects which are too small to be conveniently held in the bench vice or by hand, and which require the same manipulation as if they were held by hand. Many of these vices are similar in shape and design to the old-fashioned leg vice; an example is given in Fig. 112. Another useful type of hand vice is shown in Fig. 113. The jaws are made of forged steel, and the handle of case-hardened malleable iron. A hole through the

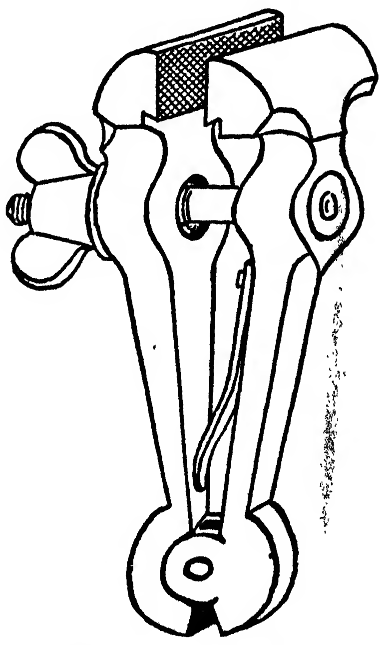


FIG. 112.—Large Hand Vice.

handle allows of wire or small drills being held without fear of slipping.

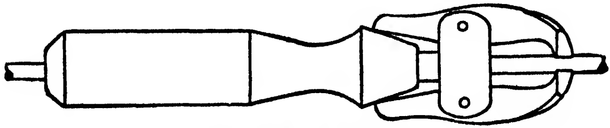


FIG. 113.—Hand Vice.

Pin Vice.—An extremely useful type of vice is shown in Fig. 114. This consists of a handle, a chuck, and a tapered nose. The chuck or collet has hardened steel

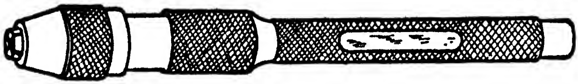


FIG. 114.—Pin Vice.

jaws arranged so that when the handle is turned the jaws will firmly grip any round piece of metal inserted in them. The hole extends through the full length of the handle, which is reduced in size, so that it may be easily rotated between the thumb and finger when filing small work. It is particularly useful for holding small files.

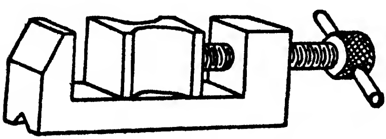


FIG. 115.—Toolmaker's Vice.

Toolmaker's Vice.—This type of vice is particularly useful for holding small work which requires filing or drilling, and for such work as laying out small jobs on the surface plate. It is usually made of mild steel, case

hardened, and takes the form shown in Fig. 115. It is light and convenient to handle, and can frequently be held by hand during machining or fitting operations. Another

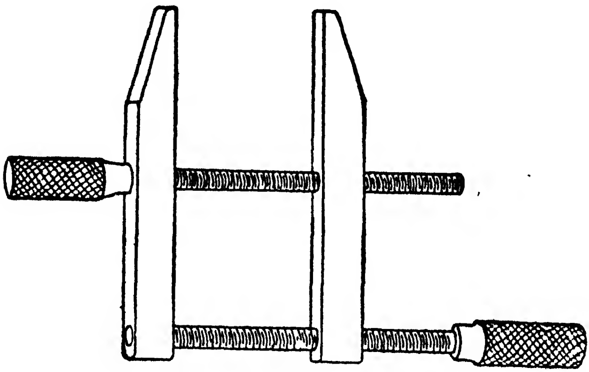


FIG. 116.—Toolmaker's Clamp.

useful tool for the toolmaker is the clamp shown in Fig. 116.

Vice Clamps.—The jaws of all engineers' vices, being faced with hardened steel, are very liable to cut or bruise any work which is firmly held; therefore, when light or delicate work has to be held, it is necessary to use something to prevent damage to the work. For this purpose clamps are used; these can be conveniently made from sheet aluminium, iron, brass, or copper.

FIG. 117.
Vice Clamp.

A simple form of vice clamp is shown in Fig. 117. These can be made from any of the above metals or from lead. It is usual to find in most shops an iron mould for making lead clamps, so that those worn out can be

melted and recast, as necessary. A very useful type of vice clamp is shown in Fig. 118. It is chiefly employed when spindles or bars have to be held in the vice. For such purposes as holding round work when cutting keyways, it is indispensable, as it allows of the shaft being turned round without the necessity of taking the weight by hand each time it is required to move it in any way.

FIG. 118. Vice Clamp for Round Work.

Vice Clamps for Round and Special Work.—Vice clamps for holding round and special work can often be designed in such a manner as to save a considerable amount of time in carrying out a particular job. An example is given in Fig. 119. Here the clamp consists of

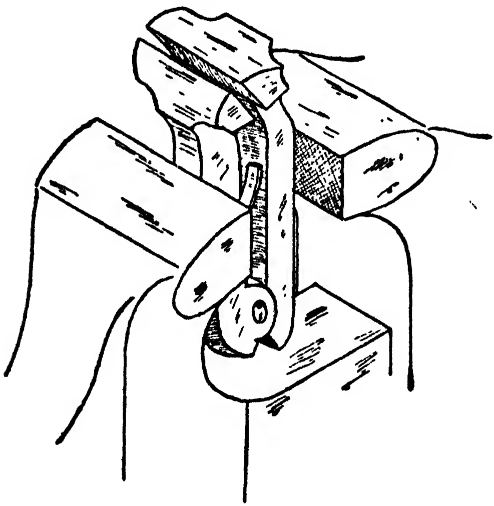


FIG. 119.—Auxiliary Vice.

an auxiliary vice very similar to the hand vice shown in Fig. 112, but without the thumb screw and with the jaws set at an angle.

For holding small tubes in order to flange or screw the

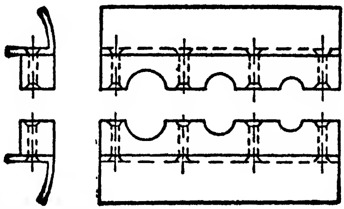


FIG. 120.—Vice Clamp for Flanging Tubes.

ends, the arrangement shown in Fig. 120 will be found very convenient. A hole is chosen slightly smaller than the outside diameter of the pipe, and the clamp will then be found to grip the tube sufficiently tightly for all

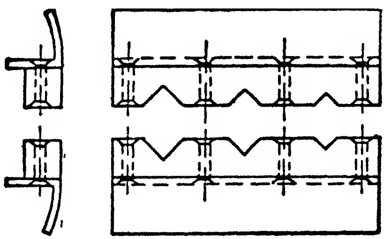


FIG. 121.—Vice Clamp for Special Work.

practical purposes. Another type of clamp is shown in Fig. 121. This also will grip round work of various sizes.

Filing Blocks.—As it is often impossible to hold thin work between the jaws of the bench vice, filing blocks are necessary. The simplest form consists of a piece of flat

wood of suitable size held in the vice, the work being placed on top and held in position by means of a few wire nails, the nails being driven just below the surface of the

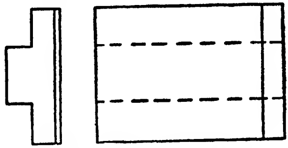


FIG. 122.—Filing Board.

metal. A more useful form is that shown in Fig. 122. Here provision is made for the block to rest on the top of the vice, and a piece of wood is nailed to the surface to prevent the work from sliding off while being filed.

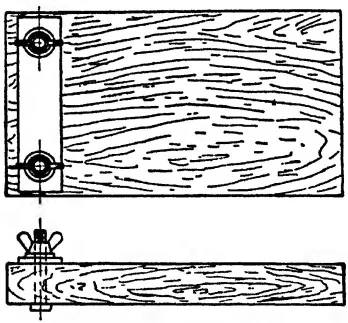


FIG. 123.—Filing Board.

A filing board is shown in Fig. 123. This is a board fitted with a clamping plate, and will be found useful for holding thin metal of which a part only requires filing.

Holding Work in the Vice.—Considerable practice is required before the student or apprentice can judge exactly how tightly a job can be gripped in the vice. It is quite an easy matter to spoil or distort a light or delicate piece of work, and great care should be exercised when holding non-ferrous metals, or any specially important jobs.

Hammers.—The ordinary engineer's hand hammer, or chipping hammer as it is sometimes called, is shown in Fig. 124. The maximum weight for general chipping is around 1½ lbs., but for a wide range of work a smaller

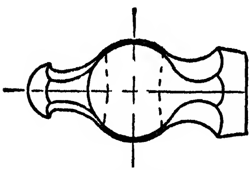


FIG. 124.—Engineer's Hand Hammer.

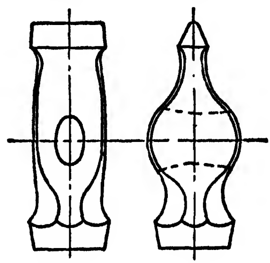


FIG. 125.—Cross Pene Hammer.

size of, say, ¾ or 1 lb. weight are preferred. The ball-shaped end is called the "pene" and is chiefly used for riveting purposes. Hammers of the same weight are frequently used with the pene shaped as in Fig. 125. This is called a cross pene hammer, and when the pene part of the hammer runs in the opposite direction, that is, when in line with the handle, it is termed a straight pene hammer.

Sledge Hammer.—Sledge or flogging hammers weigh from 7 to 14 lbs. and have two flat faces. They are chiefly used in the forge and occasionally in the fitting and erection sections for such purposes as keying, and driving wheels on shafts, and other jobs where a heavy blow is essential.

Riveting Hammers.—Special riveting hammers generally have one ball pene, the other end of the hammer being lengthened to as much as 6 in. with a flat face; this lengthening of the hammer allows of riveting in corners and gives access to awkwardly placed rivets.

Lead, Copper and Hide Hammers.—A heavy lead or copper hammer is a most useful tool in the fitting shop. It consists of a piece of round or square cast metal fitted with a wooden handle, and can be used for giving heavy blows to a job without much fear of badly bruising or damaging the job; it is often used for giving a blow to the end of a large spanner when tightening up bolts.

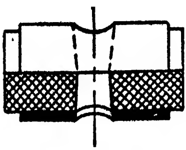


FIG. 126.
Hide Faced Hammer.

A hide hammer sometimes takes the form of a simple round hammer made by rolling raw hide into the shape of a solid cylinder. Another form of hide hammer is shown in Fig. 126. This is made from a piece of tube fitted with a handle and partly filled with leather, the hide projecting a short distance from the ends of the tube.

Chipping.—Before the introduction of the machine tool on a large scale, a great amount of work was accomplished by means of the hand chisel, but under modern conditions it is uneconomical and inexpedient to use the hand chisel to any great extent, with the result that chipping is now seldom necessary. When it is not possible to use a machine tool, chipping is often carried out by means of the pneumatic chisels; but even in the modern and up-to-date shop it is sometimes less costly and more expedient to do certain pieces of work by means of hand chipping, and in these special circumstances, or when rapid repairs are required in out of the way places, the ability to use the

hammer and chisel in a quick and accurate manner is often of the greatest possible service.

Chisels.—Chisels are made from both plain carbon and alloy steels and vary in length, section, and shape, according to the particular work they are intended to do.

It is usual to forge chisels from bar steel of the same section as that required for the chisel, the ends being simply heated and hammered to the shape desired. The cutting edge is then ground on the wet emery wheel to the correct angle. The cutting angle given to the chisel is determined by the nature of the metal to be chipped; it varies between 40° and 70°, the less acute angles being for the harder and tougher metals.

The following may be taken as approximate cutting angles for chipping various metals:—

For cast steel	70°	For wrought iron	50°
For cast iron or hard bronze	60°	For copper and brass	40°

The *flat chisel* shown in Fig. 127 is used for chipping large surfaces and for general cutting purposes.

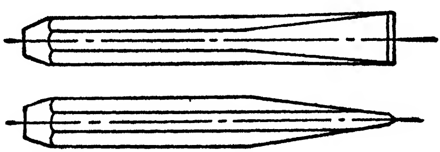


FIG. 127.—Flat Chisel.

The *cross-cut* shown in Fig. 128 is suitable for cutting channels in large surfaces previous to using the flat chisel, and is also used in cutting keyways in wheels and shafts.

A *round-nose* chisel is shown in Fig. 129, and is particularly useful in cutting oil channels in bearings or pulley bushes, or for use when drawing over the centre of

holes which have run out of truth when being drilled in the drilling machine.

The *diamond-point* chisel is chiefly used for cutting cast-iron pipes, or chipping through flat plates, and is shown in Fig. 130.

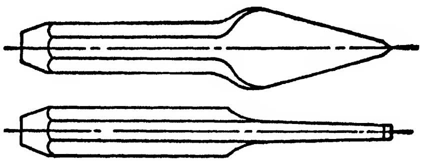


FIG. 128.—Cross-Cut Chisel.

A most useful chisel is shown in Fig. 131. This is known as a *side chisel*, and is particularly useful in chipping and removing the surplus metal in cottar ways and slots, which may have to be cut by hand after having been drilled.

Using the Chisel.—A considerable amount of practice

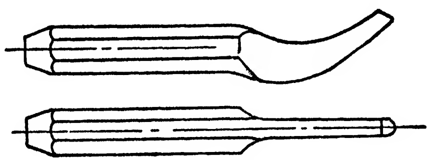


FIG. 129.—Round-Nose Chisel.

is required in order to chip the surface of a piece of metal quickly and accurately.

When chipping, the chisel should be held chiefly with the second and third finger, the index finger being relaxed. The hammer shaft should be grasped at the end, and when in use should be brought up square with the body and nearly to the shoulder. The angle the chisel should be

held at in relation to the work depends to some extent upon its cutting angle, but can be best determined by actual practice. A little practice, after being shown the correct method, will be of more use to the student than detailed explanations.

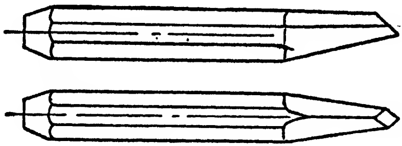


FIG. 130.—Diamond-Point Chisel.

Brass and cast iron are usually chipped without the aid of a lubricant, but for chipping wrought iron and steel a little oil will improve the cutting action.

When chipping large surfaces a number of narrow grooves are first cut across the surface of the metal, about $\frac{3}{8}$ in. wide

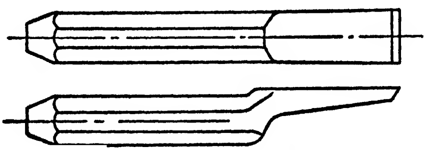


FIG. 131.—Side Chisel.

and about $\frac{7}{8}$ in. apart. If the depth of each groove is the same, it only remains to chip away the surplus metal with a flat chisel, using a straight edge to test for flatness.

Chipping towards the edge of a piece of metal should be avoided, because of the liability to fracture the corners. All chisels should be kept sharp. They will then cut well, and give good results.

Filing.—Some skill and practice is required before the file can be used with any degree of accuracy, and the filing of a flat surface is a difficulty only to be overcome by practice. In using the file, it is best to stand directly in

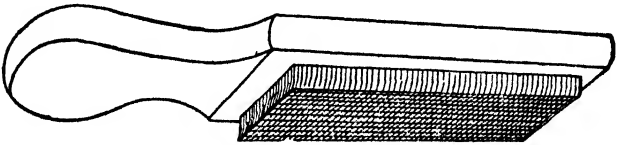


FIG. 132.—File Card.

front of the work, with the left foot advanced about 24 in., holding the end of the file in the palm of the hand, with the handle up against the ball of the right thumb. When cutting, long steady strokes should be taken, putting on

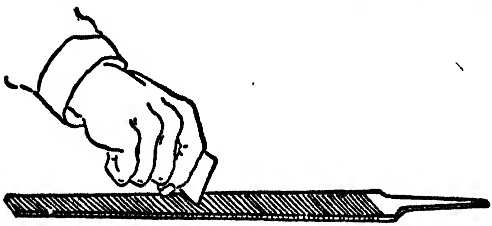


FIG. 133.—Clearing File Teeth.

weight in the forward stroke, and relaxing on the backward, at the same time keeping the file perfectly horizontal. Any rocking will produce a convex surface.

Cross Filing and **Diagonal Filing** should be used when large surfaces or a large amount of metal has to be removed. Owing to the cuts or grooves formed by the file coming at an angle to one another, a true surface is more likely to be produced.

Draw Filing is a useful method of finishing or polishing metal. The file is grasped in both hands and drawn in one direction along the surface of the work. This brings all the grooves or scratches in one direction, and gives a finished appearance to the work.

When using smooth or dead smooth files on fibrous metals, the teeth will be found to clog or pin, and if they are not cleared the file will be found to badly scratch the work. With practical experience of filing this can be avoided to a great extent, but the teeth must be kept cleared by means of the file card, which is shown in Fig. 132, or by means of a strip of thin metal, as shown in Fig. 133. A little chalk rubbed on the teeth of the file will help to prevent this pinning of the file teeth taking place to any great extent.

New files should always be kept for filing brass or copper alloys, and when the edge has worn off somewhat, they can be taken for use on the harder metals.

Files

Files are graded and classified according to their section, spacing and depth of teeth, and length. They are forged by power or hand from carbon steel, the tangs being generally drawn down afterwards by hand. After forging roughly to size, they are annealed and ground on coarse grindstone to the size and shape required. The teeth are cut by hand or machine, and the file is then hardened by heating to a cherry red and quenching in a solution of salt and water.

The teeth are graded, as shown in Fig. 134: A, rough; B, middle; C, bastard; D, second cut; E, smooth; and F, dead smooth.

All these grades are given to both single and double

cut files. The spacing of the teeth is generally as follows:—

Rough, 20 teeth per inch.
Bastard, 20 to 25 teeth per inch.
Second cut, 30 to 40 teeth per inch.
Smooth, 50 to 60 teeth per inch.

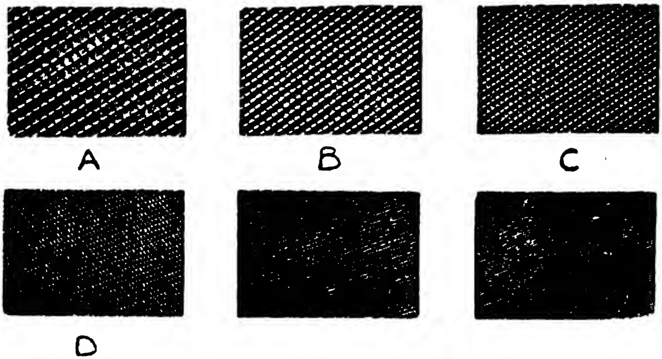


FIG. 134.—Grading of Files.

The single cut file is shown in Fig. 135, the angle θ being about 15°. With the double cut file, Fig. 136, two

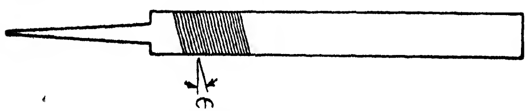


FIG. 135.—Single Cut File.

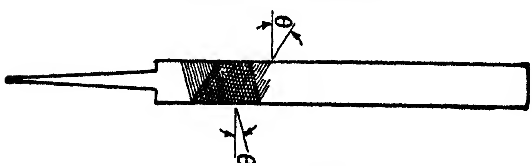


FIG. 136.—Double Cut File.

separate cuts are made, one crossing the other, as shown. The angles vary according to the size and grade of the file; for the bastard cut on a 12-in. file they would be about 20° and 40° respectively.

Taper and Parallel Files

What is known as the parallel file is usually slightly tapered in thickness, but all grades may be obtained with a safe edge, that is, one edge free from teeth and quite

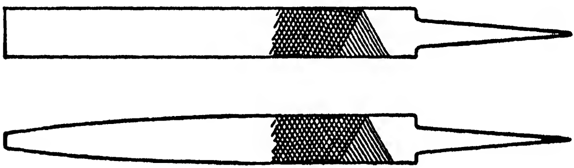


FIG. 137.—Taper and Parallel Files.

smooth. The taper file is actually tapered in width, as shown in Fig. 137.

Length of Files.—Files vary in length from 3 in. to 16 in., but those in general use are from 4 in. to 14 in.

File Sections.—The sections of files in everyday use are shown in Fig. 138: A being the square file; B, three-square or triangular; C, round; D, half-round; E, flat file; F, flat hand file; G, cottar; H, barrette; I, triangular or saw file; J, double half-round; K, diamond; L, saw file; M, cabinet; N, cross cut; O, oval file.

Special Files

Many special files are in common use; these include Swiss files with very fine teeth, block files, and files of unusual shape for special purposes.

Setting Files.—When it is found impossible to reach the surface to be filed in the ordinary manner with a straight file, as would be the case in filing a key-seating, the file can be heated and set, as shown in Fig. 139. To set the file, it should be heated to a dull red, and struck

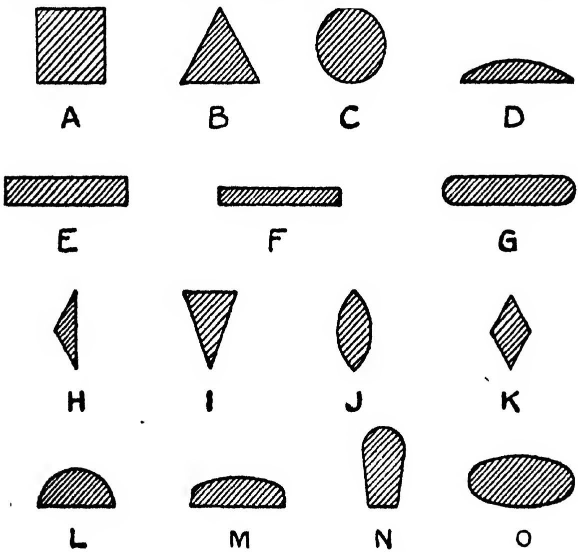


FIG. 138.—Various Sections of Files.

with a lead or wooden hammer while lying on a block of lead.

File Handles.—File handles are made of wood, compressed paper, and iron. It is important that the file should fit the handle quite straight with its axis. To do this in a proper manner it is necessary to heat the tang of the file, and burn a hole in the centre.

Special file handles are made to enable the file to be used on a surface which may be below the surrounding parts.

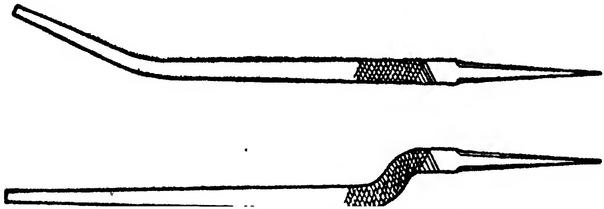


FIG. 139.—Set Files for Filing Keyways.

Examples of special handles are shown in Figs. 140 and 141. For a similar purpose block files are made; these are

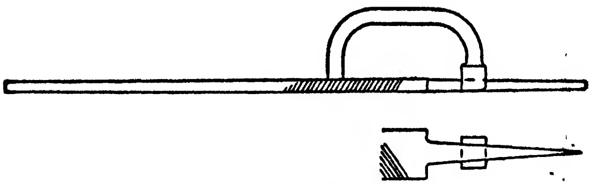


FIG. 140.—Special File Handle.

square or oblong in section, and are provided with holes on all sides into which a bent handle, fitted with a pin, can be inserted.

FIG. 141.—Special File Attachment.

Scraping

In spite of the introduction of the grinding, honing, and fine boring machines it is still necessary in a number of instances to use the scraper so that the desired surface finish and fit may be obtained.

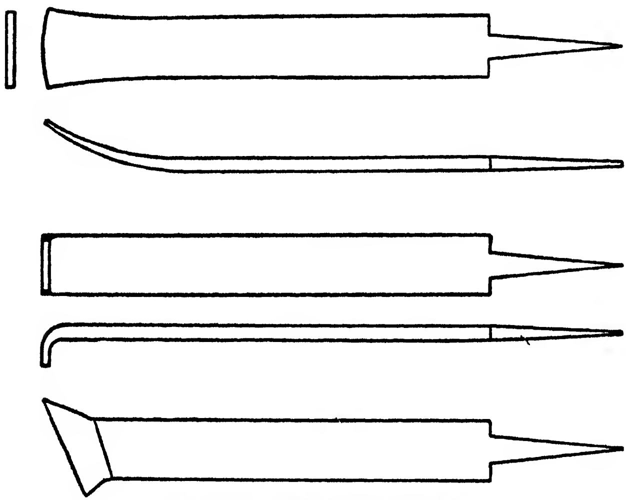


FIG. 142.—Examples of Scrapers.

Scrapers vary in size and shape, according to the particular work for which they are required. It is quite common to make them from old worn-out files. These are heated at one end, hammered out or bent, and then ground smooth. After this they are hardened and tempered, first by bringing the cutting edge to a blood red and dipping into water, and then tempering by holding it close to a red-hot piece of iron until a light straw colour is obtained. The cutting

edges of a flat scraper are ground to an approximate angle of 90°, whilst the half-round type have a cutting angle of, say, 70°. After the heat treatment and grinding, the cutting edges are stoned to suit the individual.

A number of scrapers are shown in Fig. 142, and these can be used as convenient for the work in hand.

A set of smaller scrapers are shown in Fig. 143. These are intended more for toolmakers; they will be found

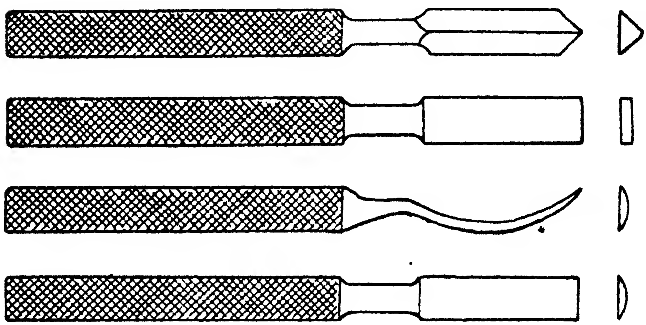


Fig. 143 —Toolmaker's Scrapers.

convenient for work on gauge making and fine fitting and adjustments.

Scraping Flat Surfaces.—For the purpose of scraping flat surfaces, a surface plate similar to that shown in Fig. 144 is required, also a flat scraper and a little marking. Before commencing scraping, all tool marks should be removed with a smooth file, and the surface filed approximately true.

The surface plate is then rubbed over very lightly with a small amount of marking, which is a mixture of black lead or red lead and oil, and the work is then rubbed on

the plate. The job can then be held in the vice, and all the transference marks scraped off. This operation is repeated until the binding points are showing over the entire surface.

When scraping a surface, care must be taken to see that no part of the work slides off the surface plate during the time it is being rubbed on for marking purposes. It is therefore necessary to have the surface plate a good deal larger than the work being tested.

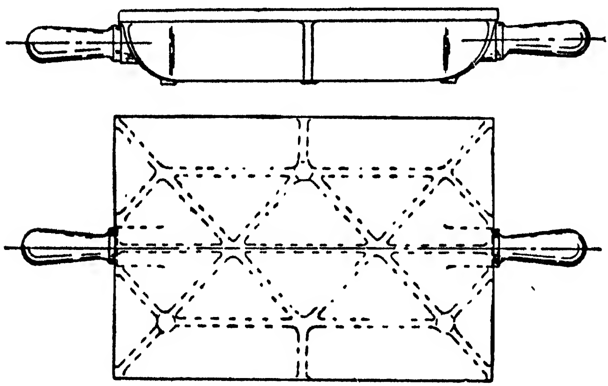


FIG. 144.—Surface Plate.

Scraping Bearings

Scraping Bearings.—Large bearings are generally lined with some kind of anti-friction metal, and are therefore easy to scrape. This is done with flat, half-round, and right-angled scrapers, similar to those shown in Fig. 142. For the purpose of testing the brasses, the journal or bearing on the shaft is rubbed with marking, and the brasses lifted into place and twisted round. Where it is not possible to do this, such as in the case of a large

bearing, skeleton mandrels are provided, and the surfaces of these are marked and used as surface plates. No special difficulty should be met with in scraping, but to accomplish quick, accurate work a fair amount of practice is necessary.

Frosting.—To give a better appearance to work that has been scraped, it is often frosted; this does not in any way increase the accuracy, and is done simply for effect. To produce this, it is first necessary to keep all the scraping in one direction, after which small squares can be scraped with a narrow scraper, either at right angles or diagonally as desired. An oil slip can be made to produce the same effect, and is to be preferred, as it does not remove so much of the metal as the scraper.

Keyway Cutting and Key Fitting.—While in most cases keyways are cut by means of a key-seating machine, lathe, miller, or some other form of machine tool, it sometimes occurs that it may be cheaper or quicker to cut them by hand.

Should this be necessary, a cross-cut chisel of the same width as the keyway is used.

It is first necessary to chip or file a flat the same width as the keyway. This is first marked out either by means of a box square or the scribing block.

The keyway is then chipped to nearly the correct depth, and if necessary it can be filed flat on the bottom with a square file, or if it is a feather keyway, it can be filed with a bent file.

Key Fitting.—After the keyway in the shaft and wheel has been cut to the correct depth and width the key can be fitted. The key is first machined all over to nearly the finished size. The key is then tried in by tapping it with a hammer. When it will drive in about half way the keyway should be rubbed with marking; this will show the spots on the key which require filing away.

The process of driving in the key, marking, and removing the hard places that are shown must be repeated until the marks show over the whole of the top and bottom surfaces, and the key is within $\frac{1}{2}$ in. of being right home. The sides of the key should be made to fit, but need not be so accurate as the top and bottom.

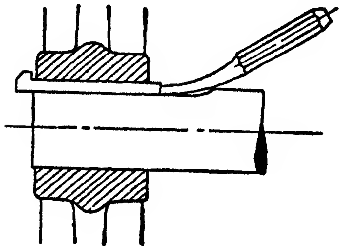


FIG. 145.—Method of Using Key Drift.

Removing the Key.—When applicable, the best method of removing a gib head key, shown in Fig. 145, is by means of a key drift.

When the key is very difficult to remove it can often be overcome by driving the wheel further on the shaft.

It should be remembered that a little oil rubbed on the key and in the keyway will often prevent the parts seizing together, and save a large amount of time and work.

Key Proportions.—The standard keys are of two cross sections, square and rectangular, and in all instances reference should be made to the appropriate standard as listed by the B.S.I., the S.A.E., or the A.S.A.

Hand Reaming

The reamer is a tool for producing a perfectly smooth hole of standard size, and sometimes consists of a round piece of carbon steel, part of which is machine-cut, with spiral or parallel flutes, in such a manner as to produce cutting edges; it is then hardened and tempered, and afterwards ground accurately to size. Hand reamers are generally of the fluted type, having the cutting edge along

each flute. So that the tool may readily enter a drilled hole, the front edge of the reamer is made slightly taper. With some designs the front portion is given a thread so as to produce a self-feeding tool, but this class of reamer does not appear to have found general acceptance in the shops. The means of holding a hand reamer is identical with that for a tap, the back end of the shank being machined to give a square section for gripping in the tap wrench.

The Cincinnati Co. of America carried out a series of tests to find the best clearances for various classes of reamers, and the following table shows the most satisfactory results for hand reamers. Table I. is for hand reamers cutting cast iron, and Table II. for cutting steel.

Size of Holes for Reaming

For hand reaming it is usual to leave in between .002 and .004 in. to be removed with the reamer. Reaming holes in two different classes of metal is frequently difficult, and where one metal is hard and the other soft, the tendency is for the hole in the soft metal to finish rather large. Expansion reamers have a number of advantages over the solid reamer. For large work especially, the saving in cost is considerable, but unless they are made with great accuracy it is necessary to regrind them after each readjustment.

Reamers are made parallel, and tapered both for roughing and finishing. Fig. 146 illustrates various types of reamers for hand use. These are manufactured by the Birmingham Small Arms Co., and show at Fig. A a taper reamer for roughing out; Fig. B a taper reamer for finishing; Fig. C the ordinary type of parallel hand reamers; Fig. D an adjustable hand reamer for reamering blind holes; and Fig. E the same type of reamer for through holes. A plentiful supply of oil should be used when reaming wrought iron or steel.

Hand Reamers

FIG. A.—Roughing Taper Reamer.

FIG. B.—Finishing Taper Reamer.

FIG. C.—Parallel Hand Reamer.

FIG. D.—Adjustable Hand Reamer for Blind Holes.

FIG. E.—Adjustable Hand Reamer for Through Holes.

FIG. 146.

Reamer Clearances

Table I. For Cutting Cast Iron. *Clearance Land ·025 in. wide.*			Table II. For Cutting Steel. *Clearance Land ·005 in. wide.*		
Size of Reamer.	For Cutting Clearance.	For Second Clearance.	Size of Reamer.	For Cutting Clearance.	For Second Clearance.
In.			In.		
1/2	·032	·072	1/2	·012	·052
9/16	·032	·072	9/16	·012	·057
5/8	·032	·072	5/8	·012	·062
11/16	·033	·095	11/16	·012	·067
3/4	·035	·095	3/4	·012	·072
13/16	·037	·095	13/16	·012	·077
7/8	·040	·120	7/8	·012	·082
15/16	·040	·120	15/16	·012	·087
1	·040	·120	1	·012	·092
1 1/16	·040	·120	1 1/16	·012	·097
1 1/8	·040	·120	1 1/8	·012	·102
1 3/16	·042	·122	1 3/16	·012	·106
1 1/4	·045	·145	1 1/4	·012	·112
1 5/16	·045	·145	1 5/16	·012	·118
1 3/8	·045	·145	1 3/8	·012	·122
1 7/16	·045	·145	1 7/16	·012	·127
1 1/2	·048	·168	1 1/2	·012	·132
1 9/16	·050	·170	1 9/16	·012	·137
1 5/8	·050	·170	1 5/8	·012	·142
1 11/16	·050	·170	1 11/16	·012	·147
1 3/4	·052	·192	1 3/4	·012	·152
1 13/16	·052	·192	1 13/16	·012	·157
1 7/8	·056	·196	1 7/8	·012	·162
1 15/16	·056	·196	1 15/16	·012	·167
2	·056	·216	2	·012	·17[illegible]

Drifting or Broaching

Broaching or drifting is the process by which holes of various shapes are formed in metal by forcing or driving a drift of the required shape through holes that have been previously drilled or roughly formed. To form square or

rectangular holes in work by means of the file takes a considerable amount of time, and a much quicker method is to first drill a hole, then roughly chip it out to size and shape, and afterwards broach it out accurately by means of a drift.

Broaches or drifts are made from carbon steel, formed to the shape required, with the sides left smooth, or cut to form serrated teeth.

Case-hardened low carbon steel has proved very satisfactory for some broaching operations.

A great number of broaching operations are done on special broaching machines, and modern methods allow quite intricate work to be carried out very rapidly and with a high degree of accuracy.

Marking Out Work

Marking out work, either for fitting or machining, will at some time or other bring into use the marking-off table, the scribing block, squares, and, in fact, most of the tools mentioned in Chapters I., II., and IV.

Centring Round Work.—The simplest and quickest method of finding the centre of a piece of round bar is by means of the centre square, shown in Fig. 147. If the work is quite circular this method is satisfactory. When, however, the work is not quite round, the centre can be found approximately by means of the "Jenny," as seen in Fig. 148. Here four arcs are scribed on the centre of the work, and these are arranged so as to leave a small square, in the centre of which will be the centre of the work.

In centring work for the lathe, the usual method is to place the work on two or more vee blocks in such a manner that it can be freely rotated. The scribing block is adjusted so that the scriber point is near the centre of the job, and a line is drawn, as shown at A in Fig. 149. Without shifting

the job, a line is also scribed at the other end of the work. The work is then given a half turn, and another line is

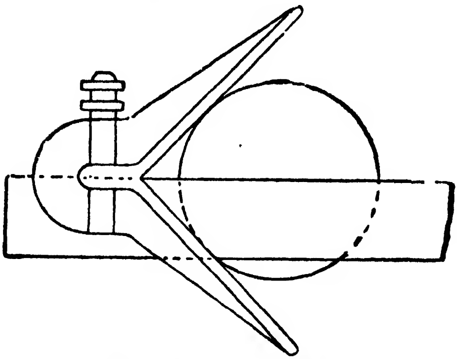


FIG. 147.—Centre Square.

drawn, as at B in the illustration; this is also repeated at the opposite end. The work is then given a quarter turn, and C is scribed on both ends. Then another half turn is

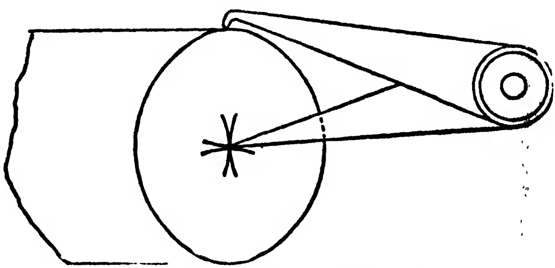


FIG. 148.—Finding Centre of Cylindrical Work.

given, and D is scribed. The result of scribing the four lines at each end of the work is that a small square is made, and the centre of the square must be the centre of the job.

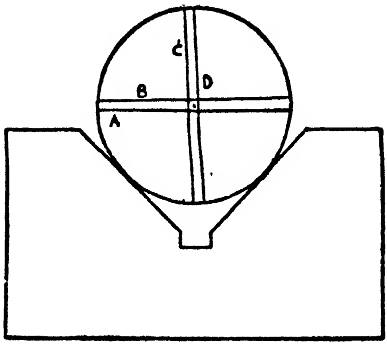


FIG. 149.—Method of Using Vee Blocks.

Vee Blocks.—An extremely useful type of vee block is shown in Fig. 150. This is machined all over, and has four vees of different sizes, on which a large range of work can be laid.

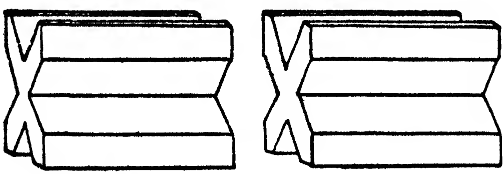


FIG. 150.—Improved Form of Vee Blocks.

Marking Out for Machining.—Work which requires machining is first lined out by means of scribers, dividers, squares, and various other tools, and is then carefully dotted, as shown in Fig. 151. The placing of these dots acts as a guide and also a witness. In the absence of dots, lines are liable to be rubbed out, especially if water has to be used as a lubricant. The dots, after fitting or machining,

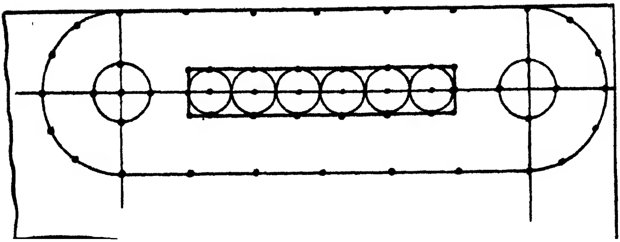


FIG. 151.—Marking Out for Drilling and Fitting.

will still be visible, because only half the dots will be removed. The presence of half-dots on a finished surface is not always permissible, hence care is necessary. In marking work, the dots should be evenly spaced and made of equal size. Centre dots for drilling can be made considerably larger.

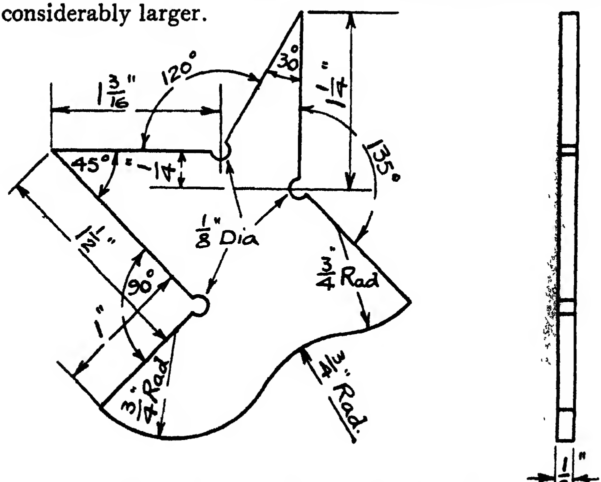


FIG. 152.—Exercise in Marking Out an Angle Gauge.

Fitting Exercises.—A good example of a job requiring careful marking out is shown in Fig. 152. This should be made from cast steel, and if carefully fitted will be found to be a very useful tool.

Another fitting job is shown in Fig. 153. The material is $\frac{1}{16}$-in. cast steel, and $\frac{7}{8}$-in. by $\frac{1}{4}$-in. mild steel. The method of making this square would be as follows:—

1. Cut the blade about $\frac{1}{16}$ in. larger than the finished size and file it very accurately to the given measurements.

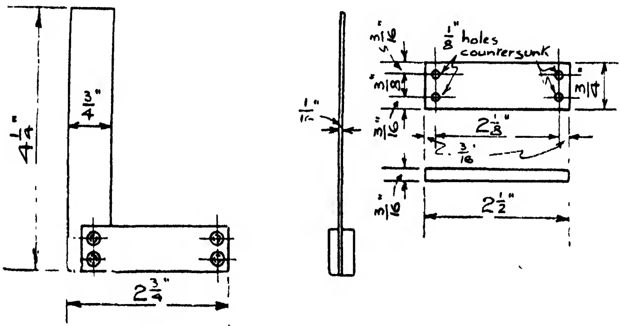


FIG. 153.—Details of Built-up Try Square

The face can be finished by placing the work on a flat piece of hard wood and holding it in position by means of a few small brads.

2. Cut off two pieces of mild steel $\frac{1}{16}$ in. longer than finished size. Carefully file one end, one side, and one face of each piece quite square and flat.

3. Mark off the holes on one of the side pieces, and drill to gauge size.

4. Place the three pieces in their correct position on a surface plate, and clamp them together. When they are

quite flat on the inner faces, drill through the blade and the other half of the stock, and then slightly countersink the outsides of all holes. Take apart, and file off any burrs.

6. Cut off pieces of $\frac{1}{8}$-in. round mild steel to length, allowing for riveting, and drive in.

7. Finish stock by filing the side and end, using a micrometer to test the work. Great accuracy can be obtained by using the surface plate and flat scrapers.

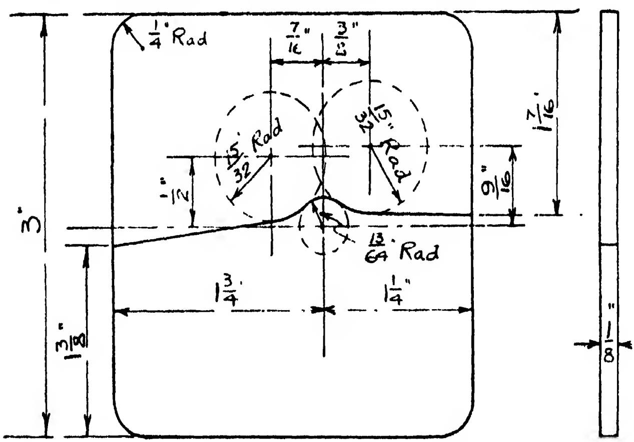


FIG. 154.—Marking Out Gauge Plates.

A further example in marking out and fitting is shown in Fig. 154. Considerable care must be taken in the marking out, and accurate fitting will only be obtained by careful use of the scraper.

The Engineer's Square

The engineer's square, or try square, is one of the commonest tools used by the fitter and machinist; it is used for testing surfaces at right angles to each other and for scribing lines laying at 90°.

Steel squares are made in three different types. In one type the blade and stock are formed from one piece of thin rectangular section steel, afterwards hardened and tempered, and provided with graduations on one or more edges. Another type has a thin, narrow blade fitting into, or forming part of, a much thicker stock, both of rectangular sections. An improved type, intended for particularly accurate work, has bevelled edges on the blade in order to obtain line contact with the work. The most accurate and satisfactory squares are machined from a single piece of tool or cast steel, hardened and tempered and ground accurately to size.

In addition to the types of squares mentioned, there is another tool, frequently used for similar purposes, called a combination square. This differs from the try square in that the head forming the stock can be moved to any position along the blade and clamped in position, and combined with the adjustable square is a mitre and a bevel. This tool provides a try square in which the length of the blade can be varied to suit special requirements, and one which will determine whether surfaces are level or plumb.

The combination square includes, in addition to the square, a protractor and a centre square. The blade of the former can be set to any angle desired, and the latter can be used for finding the centre of cylindrical pieces of work. The tool can also be used as a depth gauge or height gauge.

Testing a Try Square

A simple and quick method of testing a try square is to lay the blade of the square flat on a surface plate with the stock firmly pressing up to the machined edge. Scribe a line along the edge of the blade, and then turn the square completely over and scribe another line over the top of

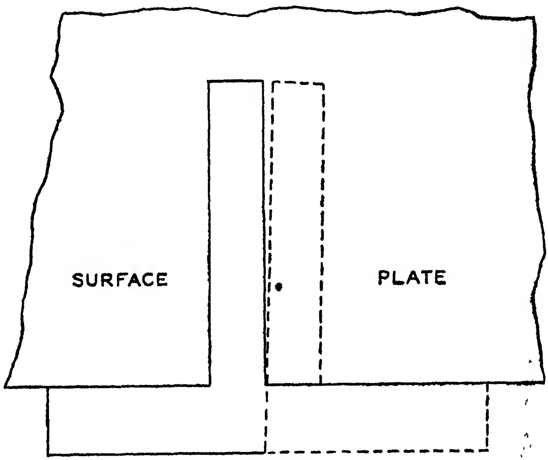


FIG. 155.

the first line. If the square is true the lines will appear as one, but if inaccurate the lines will not coincide but will form an angle between them, as shown in Fig. 155.

Another method of testing or adjusting try squares is by using four flat discs; their diameter is immaterial provided they are in proportion to the size of the square and that their limits of size are within $\frac{1}{10000}$ in., which

is closer to absolute accuracy than the ordinary tool-room try square.

To test the square, lay the discs and square on the surface plate, as shown in Fig. 156; then, with a micrometer, measure the distances AB and CD. If they coincide, then the lines HJ and JK must form a right angle. Any deviation from an angle of 90° will multiply the difference

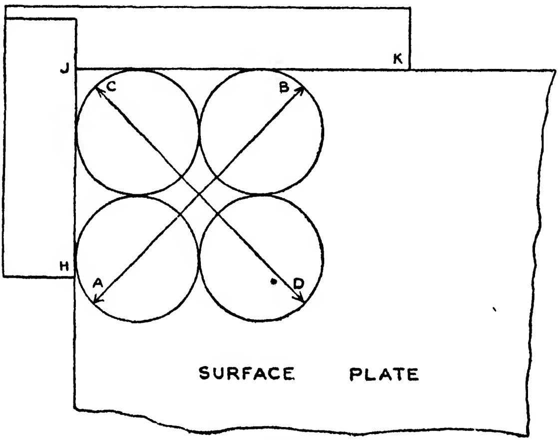


FIG. 156

between the two pairs of discs by two; thus if the distance AB is less by 0.001 in. than it should be for an angle of 90°, then the other two discs will be pushed 0.001 in. apart, making the difference in the two measurements of 0.002 in. This makes the test an extremely accurate one, although it only actually tests the points on the square that are touched by the discs. The edges of the stock and blade should be made as near to perfect straight edges as possible before the test is applied.

Care of Try Squares

Engineers' try squares, like all other accurate tools, require careful handling. They should be kept clean and oiled, and when not in use should be laid in a suitable wooden case.

CHAPTER VI

MATERIALS

WHILE steel manufacture, forging, rolling mill, and foundry practice cannot be placed under the strict heading of "Engineering Workshop Practice," a general knowledge of the materials used is essential for all engineering students irrespective of age. This is necessary so that the designer may achieve his ends economically and the shopman carry out the designer's aims with intelligence. When possible, it is a good thing for a student or apprentice to spend some weeks in such departments as the foundry, pattern shop, or heat treatment section so as to gain knowledge of the preparation of the material for the machine and fitting shops.

The range of metals and alloys now available for the engineer is wide, and may roughly be grouped as follows: (*a*) The light metals covering magnesium and aluminium either in the commercially pure state or as alloys; (*b*) the non-ferrous alloys having copper as the base metal; (*c*) the zinc base alloys; (*d*) cast iron and its alloys; (*e*) malleable iron castings; (*f*) the low and medium carbon steels coming within the low and medium carbon group of constructional steels; (*g*) the plain high carbon and alloy tool steels; (*h*) the high alloy steels coming within the stainless, heat, and corrosion resisting types.

The subject of metals and alloys now available to the engineer is very large, and the information as given here

barely touches the fringe of the subject. Much, for space reasons, has had to be omitted, but it is hoped that the information given will only be the preliminary steps towards a very interesting study.

Cast-Iron Castings

Cast iron is probably the most extensively used metal in the engineering industry, and the raw material comes from the blast furnaces in two main forms: (1) as sand-cast pigs, (2) as machine-cast pigs. It may be of two main qualities: (1) a normal or ordinary cast-iron mixture as obtained by the direct reduction of the ore, or (2) as a refined iron of a special composition which often includes various alloying elements such as nickel, chromium, or molybdenum. The general tendency is, to-day, to purchase pig iron to a definite analysis, not as formerly upon the fracture.

Melting.—The melting of cast iron is usually done in a cupola similar in outline to that at Fig. 157, and this is probably the oldest and certainly the cheapest method of bringing the metal into a liquid condition. The usual charge consists of three main portions: (1) the metal which may comprise pig iron broken into suitable sizes, foundry scrap, purchased cast-iron scrap, and steel; (2) the fuel which is a foundry coke; (3) the flux such as limestone.

Where possible the cupola should be charged automatically by means of a lift or hoist, which carries the selected and correctly proportioned charge from the ground level and drops it into the cupola without dumping the materials on to a charging platform. This procedure eliminates the costly rehandling of the materials on the charging

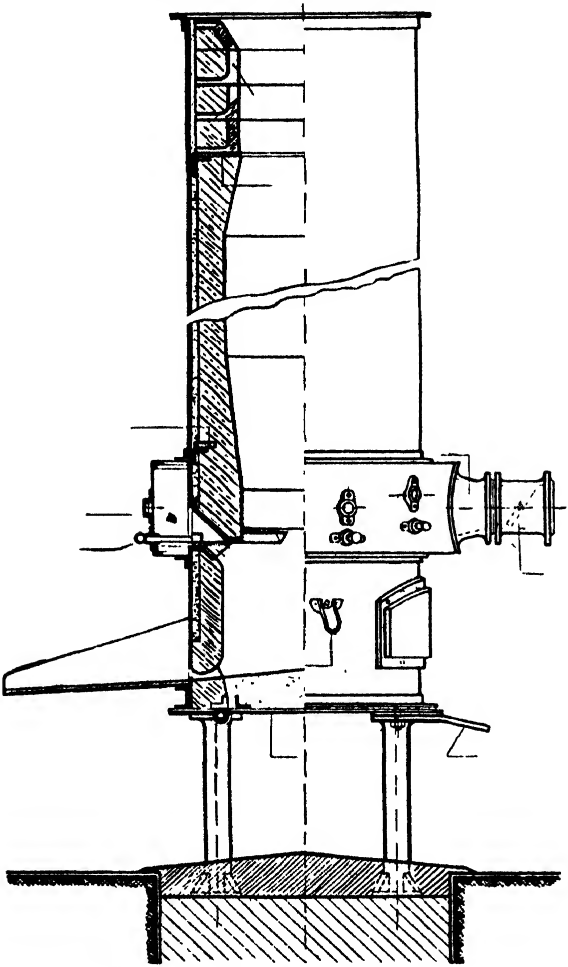


FIG. 157.—Typical Modern Cupola.

platform, enables the men to work away from the dangerous and uncomfortable conditions that often exist near to a charging door, and reduces the number of men required to keep the cupola fully charged. It is assumed that the design of the cupola includes a dust and spark arrester, so that when the blast is in operation, hot particles of coke or metal are not blown out of the stack on to the adjacent roofs, or on the personnel working in the stock yard.

The air blast from the blower should be constant and of sufficient volume to produce, at the spout, molten metal within the desired temperature range. In each instance the latter will depend upon the composition of the iron run through the cupola. Periodically the slag is run off through the slag notch.

Cast iron is also melted in either a crucible or air furnace. Often the cupola is used in conjunction with another furnace, and this is particularly so when the composition has to be held within narrow limits. In this manner the economy of melting as given by the cupola is linked with the close control of the composition obtained when using an air or electric furnace. The normal gains and losses associated with cupola operation are the pick-up in the sulphur and carbon content from the coke and the loss in silicon and manganese due to the combustion of the former and the chemical reaction of the latter with the sulphur which it carries away into the slag. By the duplex process the main composition of the iron is obtained by melting in the cupola; the molten metal is tapped off and transferred to the air furnace. At this stage the metallurgical department takes an analysis and determines what additions are required These made, and sufficient time given for the reactions to take place, another check is carried out, and if the composition is

satisfactory the charge is run into the ladles then taken to the pouring section where the moulds are held in readiness for the metal.

The usual elements in a grey iron casting of the unalloyed type are silicon up to, say, 2.5 per cent.; manganese up to, say, 1 per cent.; phosphorus up to, say, 1.5 per cent.; and sulphur which is usually under, say, 0.15 per cent. Silicon within the limits mentioned is a graphitising agent, that is, it prevents the formation of "white iron." Generally the foundryman regards silicon as a controlling element and adjusts the percentage present in any charge to suit the thickness of the article to be produced. Thus a thin article of, say, $\frac{1}{8}$ in. thickness may have a silicon content around 2.5 per cent., whilst a thick article of, say, 2 in., would only have around 1 per cent. silicon. Manganese up to, say, 1 per cent. may also be regarded as a graphitising agent in that it prevents the sulphur present from uniting with the carbon to give rise to hard white iron. The phosphorus content depends largely upon the type of ore used; for some purposes its presence is welcomed; for others the phosphorus content must be held within close limits. Sulphur is generally regarded as an impurity and is picked up from the fuel. Carbon in a cast iron exists in two forms: (1) as combined carbon which, if in excess, gives a hard "white iron" that is both brittle and practically unmachinable; (2) as graphitic carbon, being present in the form of grey crystalline plates. The Brinell hardness of grey iron may be taken as lying between 100 and, say, 180, but the white iron may be as high as 500 to 600 Brinell.

It follows from the above that by varying the composition to suit the thickness of the article to be cast the foundry can produce grey, mottled, or white iron. The range of usefulness of the two latter irons is somewhat restricted

because of their poor mechanical properties, and difficulty presented when such operations as turning, shaping, plaining, or drilling are required. Grey iron, on the other hand, machines readily, and can be cast into intricate shapes without undue difficulties. It is intensely strong in compression, takes a good bearing surface, is not readily bruised, and damps down vibratory stresses. Combined, these features have made cast iron one of the standard materials of construction, when the desired shape has to be obtained by the foundry technique.

Alloy Cast Irons

Never-ceasing experiments over many years have resulted in the production of a wide range of alloy cast irons. In this direction the chief alloying elements are, in alphabetical order, chromium, copper, manganese, molybdenum, nickel, and silicon. In order to class as an alloying element, both manganese and silicon are added in amounts well above that associated with the standard grey irons. The first thing to appreciate with regard to the use of the above alloys is the need to adjust the iron base so that silicon, phosphorus, and sulphur are correctly proportioned.

Nickel Additions.—When the composition of the base iron has been satisfactorily adjusted the effects of nickel is twofold; firstly, it acts as a graphitiser, hence in thin sections prevents the formation of white iron and hard spots, which are liable to give difficulty in the machine shop. Secondly, with the silicon content adjusted it acts as a densener, thus giving a finer grain size, improved pressure tightness, a harder material when measured with the Brinell tester, and a higher tensile strength.

By the use of a suitable composition of iron containing, say, nickel, enhanced life can be obtained in parts subjected to abrasive wear. Cylinders or cylinder liners of all sizes—from the smallest, as in automobiles, to the

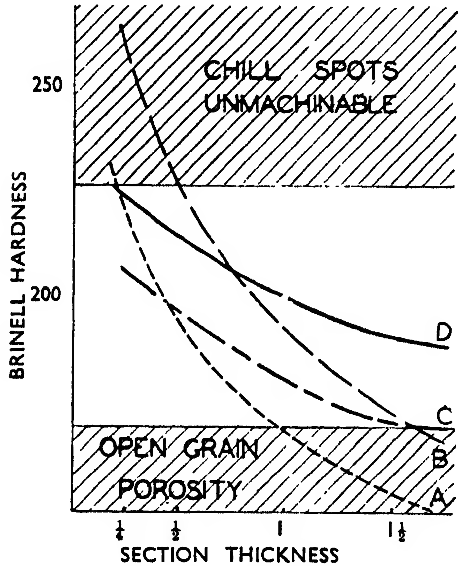


FIG. 158.—Properties of Cast Iron.

largest, as in modern marine Diesel engines—afford outstanding examples.

The value of using a nickel addition in order to obtain improved results in strength and hardness is indicated by the curves shown in Fig. 158, the Brinell hardness figures being taken as a rough criterion of strength, machinability, and density. Curve A represents a normal

soft casting, machinable, but weak and open in the thick parts. An improvement is produced by lowering silicon content (curve B), but the casting is then unmachinable in the thin parts. The best results are shown in curve D, which shows the result of adding nickel to an iron of the type illustrated by the curve B. In general, the desired results are obtained in engineering irons by the addition of 1 to 1.5 per cent. of nickel, but as the latter is a graphitiser the silicon content requires adjustment in a downward direction.

Copper.—The action of copper when used as an alloy with cast iron acts very similarly to nickel, that is, it acts as a graphitiser; but its reaction is not so powerful as nickel, so that a larger quantity within the limits of solubility is required to produce the same result.

Chromium.—Chromium is a hardener and normally used in conjunction with nickel, the one element balancing the action of the other. By adding chromium either alone or in combination with nickel and molybdenum the grain size is refined, the metal made denser, the strength and hardness increased, and the effect of mass decreased.

Manganese.—Manganese in excess of that required to control the sulphur content may be regarded as a hardening agent, so that by increasing the manganese content the Brinell values are moved upwards to around 500 to 600. For some classes of wear-resisting irons this is all to the good.

Molybdenum.—Molybdenum is also a hardener when used in cast iron and ensures a close grain, a dense material, a higher Brinell hardness value, and greater strength. It also has a nullifying action upon the mass effect, thus ensuring an even Brinell reading throughout a large section.

Silicon.—A high silicon content, around 15 per cent.,

gives a hard iron which cannot be machined but which has a high resistance to acid attack.

High Duty Irons

The use of alloy additions in irons of controlled silicon, sulphur, and phosphorus content results in improvements, not only in strength and hardness but also in all properties which depend upon density and uniformity of structure, such as wearing quality, heat and corrosion resistance, also the surface finish. The uniformity of the metal tends to eliminate casting strains, thus rendering unnecessary any long ageing treatment. Incidentally the improved density of alloy cast iron may on occasions simplify and cheapen production by enabling the foundryman to minimise or eliminate chills and denseners in the moulds.

The composition of the iron, apart from silicon, phosphorus, and the special alloy additions, will naturally depend on the particular application; generally speaking, however, alloy cast irons are used only for high-quality applications, and a good grade of pig iron should be employed. Phosphorus and sulphur must be kept low (below 0.5 and 0.12 per cent. respectively), while carbon should be controlled with the silicon, and manganese generally kept on the high side (between 0.5 and 1 per cent.), thus controlling the sulphur.

The diagram (Fig. 159) gives some idea of the strength ranges which can be attained in this type of iron; as shown by the diagram, which cannot be regarded as complete, it is of interest to note that the best strength results are obtained with a combined nickel and silicon addition.

The high duty cast-iron alloys may be produced by

(*a*) melting refined pig of the desired analysis; (*b*) by melting normal pig iron free from any alloying element, this being added as the molten metal is run into the ladle; (*c*) by the duplex process involving melting in the cupola and refining in an air or electric furnace; (*d*) by melting a charge containing a comparatively high percentage of steel and adding the alloying portion either in the cupola or when the metal is run into the ladle; in some instances

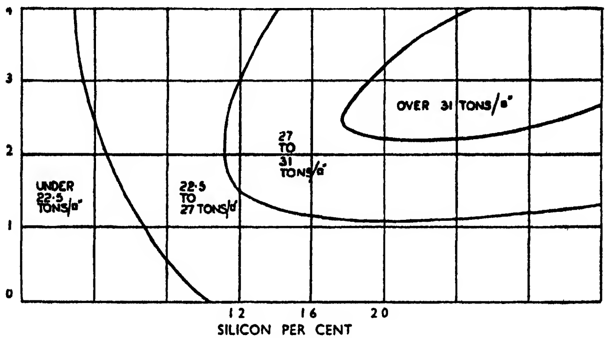


FIG. 159.—Strength of Nickel Cast-Iron Alloy.

the charge may be refined in the air or an electric furnace after being melted in the cupola. The value of using a charge with a high percentage of steel is that it brings down the silicon and carbon content and thus gives an iron which takes an excellent machined surface, is tough and resistant to shock, has a Brinell hardness value around 260°, yet offers no difficulty when being turned or drilled.

Many applications for the high duty cast-iron alloys will be suggested by their properties. For large castings they offer possibilities of reducing weight while maintaining rigidity and strength, hence are particularly

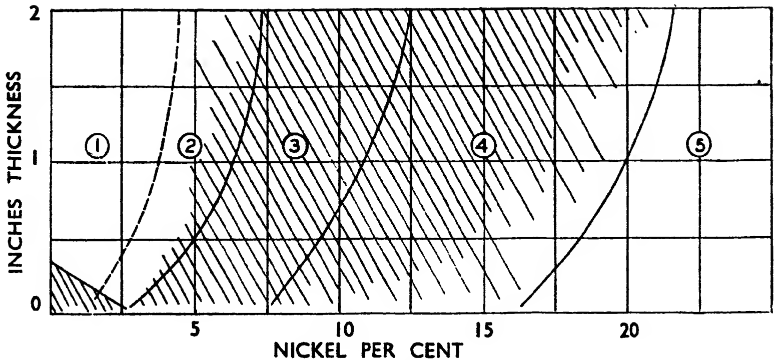
suitable for highly stressed parts, as, for example, Diesel engine frames and fly-wheels, crusher parts, rolling-mill housings, and other similar applications in the many branches of engineering practice. On account of their good wearing qualities these irons have been adopted for cylinders and cylinder liners for all types of steam and reciprocating engines, for piston rings, gears, and pinions, sheaves and pulleys, machine tool beds and frames. Their heat resistance makes the alloy irons suitable for such parts as heat exchangers, superheater headers, moulds of various types, Diesel engine heads and pistons, while a large field of useful application is found in dies for the working of sheet metal under the press. The alloy irons are dense and sound and are recommended for all applications involving pressure, as in pumps and compressors, turbine casings and valve bodies, machine tool beds, and instrument castings.

Wear, Heat, and Corrosion-Resisting Irons

The above high duty cast-iron alloys have, generally speaking, an alloy content less than 5 per cent. However, for special purposes such as resistance to abrasion, heat, and corrosion, the alloying content is moved upwards so that in some instances it reaches 30 per cent.

The general relationship between the section and nickel content is shown at Fig. 160, the area of the diagram which is sectioned being of hard martensitic structure, whilst the right-hand portion is a softer austenitic structure.

While the hardness of ordinary good quality cast iron is generally about 200 Brinell, and that of some of the high alloy cast irons already mentioned as high as 260,



Influence of Nickel on the Structure of an Average Cast Iron in various Section Thicknesses; Density of Shading indicates Difficulty in Machining.
The Composition of Base Iron is: Total Carbon 3.3%, Silicon 1.5%, Manganese 0.6%, Sulphur 0.1%, and Phosphorus 0.3%.

FIG. 160.

the hard grey cast irons obtained by adding 5 to 6 per cent. of nickel (in which the matrix is in the martensitic condition) have hardnesses of 400 Brinell or more.

The properties of the martensitic cast-iron alloys render it of outstanding value in connection with the many applications where abrasive wear is to be resisted. For example, for guide drums and rests in centreless grinding machines, where the parts have to work in contact with abrasive grit and dust, it has been found that the parts in the martensitic iron will work ten times as long between dressings as those in ordinary iron.

Perhaps the most outstanding success of the martensitic iron is in automobile cylinder liners. One manufacturer, after trying out all available materials, declared the martensitic "as cast" iron to be the best liner material he had used. Years of service experience has confirmed his decision, these liners giving him an average of 10,000 miles' running for each one-thousandth of an inch diametrical cylinder wear, as compared with 5,000 miles for the best heat-treated cast-iron liner, and only 2,000 to 3,000 miles for an unalloyed, untreated liner.

Nickel cast iron is found specially useful in withstanding caustic corrosion, and for this reason is being widely employed for caustic pots, pipes, and other castings in contact with caustic liquors. The addition of 1 per cent. of nickel gives an all-round benefit for this service, but where higher resistance is required, up to 3 or 4 per cent. may usefully be employed.

As shown in the illustration (Fig. 160), the addition of about 18 to 20 per cent. of nickel and possibly other elements gives alloy cast irons which are in the austenitic condition. In this condition an extraordinarily good resistance to corrosion and heat is obtained, while these castings have the special property of being non-magnetic.

In obtaining these properties a proportion of the nickel is often replaced by other elements such as manganese or copper.

As mentioned above, copper is used as an alloying element with cast iron, and it has been found that in the presence of nickel the solubility of copper is increased. Moreover, experience has proved that a combination of two parts of nickel with one part of copper can be alloyed with cast iron in all proportions. Under these conditions the copper assists the nickel in the production of the austenitic structure, so that, in its presence, a lower proportion of nickel will give the desired result.

Commercial austenitic cast irons have been developed with such proportions of special elements as 14 per cent. nickel, 7 per cent. copper. This composition is of practical importance since it can be readily produced by the direct addition of the well-known alloy "monel metal," which consists of nickel and copper in the required proportions of two parts to one.

Manganese may also be used in conjunction with nickel in the austenitic cast irons, one part of manganese being roughly equivalent to two parts of nickel. Here, a practical limit is found to the amount of manganese which may be added, the upper range being about 5 per cent. Above this amount the presence of manganese carbides impairs the machinability of the castings. Manganese enters into the composition of the non-magnetic cast iron "Nomag," the austenitic structure being developed by the addition of slightly more than 10 per cent. of nickel and 5 per cent. of manganese.

A very short table of twenty low-alloy cast irons is given on page 150.

No.	Composition per Cent.											Tensile.	Used for.
	T.C.	C.C.	Si.	Mn.	P.	S.	Cr.	Cu.	Mo.	Ni.	Other.	Tons.	
1	3·25	...	1·8	0·7	0·15	...	0·5	...	0·6	...	...	...	Aluminium melting pots.
2	3·1	...	1·6	0·7	...	...	0·35	...	0·35	...	...	...	Dies.
3	3·4	...	1·7	...	...	...	0·25	...	0·35	0·5	...	...	Brake drums.
4	3·2	0·6	2·0	0·8	0·21	0·07	...	...	0·5	0·5	...	22	Cams, steam turbines.
5	3·2	...	2·2	0·65	0·2	0·1	0·9	...	0·2	0·2	...	21	Camshafts for automobiles.
6	3·1	...	2·2	0·75	...	...	0·35	...	0·35	...	...	21	Clutch plates.
7	3·0	...	1·1	0·9	...	...	0·5	...	0·5	...	...	...	Cylinders.
8	3·3	0·7	1·9	0·3	0·18	0·14	0·18	...	0·18	...	...	...	Cylinders for automobiles.
9	3·2	...	2·15	0·75	0·15	0·13	0·25	0·05	0·35	1·25	...	...	Cylinder heads.
10	3·1	0·6	2·3	0·8	0·14	0·1	0·4	...	0·4	0·4	...	...	Cylinder liners.
11	3·4	...	1·6	0·85	...	...	0·35	...	0·25	...	...	...	Fly-wheels.
12	3·3	...	1·6	0·77	...	...	0·33	...	0·45	...	...	...	Furnace doors.
13	3·0	...	1·3	0·85	...	...	0·25	...	0·75	0·8	...	...	Large gears.
14	3·1	...	1·5	0·75	...	...	...	...	0·35	1·0	...	...	Lathe beds.
15	3·2	...	2·15	0·75	0·15	0·13	0·25	0·05	0·35	1·25	...	...	Oil pump bodies for aircraft.
16	3·35	0·6	2·4	0·6	0·19	0·07	0·15	...	0·5	...	...	...	Pistons, automobile.
17	3·5	0·6	2·45	0·7	0·35	0·1	0·4	...	1·1	1·0	...	...	Piston rings.
18	2·7	0·85	1·7	0·5	0·15	0·06	0·55	...	0·9	0·45	0·15 Ti	...	Pressure castings for chemical machinery.
19	3·0	...	1·9	0·9	0·2	0·12	0·4	...	0·4	1·0	...	...	Stove girders, blast furnace stoves working up to 425° C.
20	3·25	...	1·5	0·7	...	...	0·5	...	0·4	...	...	...	Zinc die-casting machine parts.

Malleable Cast Iron

An important material of the ferrous group, especially in the light engineering trades, is malleable iron. When compared with ordinary cast iron, malleable iron is less brittle and, therefore, stronger and more ductile, whilst in comparison with mild steel, which surpasses it in these properties, it has the advantage of being more fluid. On account of the special manner in which it is produced it is employed mainly for thin-walled and small pieces. As a rule the weight of parts manufactured in malleable iron is fairly light. Such parts are, for example, hinges, door keys, spanners, mountings of all sorts, gear wheels, cranks, levers, small cast parts for agricultural and textile machinery.

The heating process, usually known as annealing, has no effect on the graphite but only on the combined carbon of the casting. It is therefore necessary to start with a white pig iron. For the production of good malleable castings the correct composition of the iron used for melting is of vital importance, *i.e.*, the other elements present in the pig iron, such as carbon, silicon, manganese, phosphorus, and sulphur, must be in the right proportions.

The analysis of suitable iron for the production of malleable iron castings would run about:—

Carbon - - -	2·5 to 3 per cent.
Silicon - - -	0·6 to 0·9 per cent.
Manganese - -	0·2 to 0·4 ,,
Phosphorus - -	Less than 0·2 per cent.
Sulphur - - -	Less than 0·1 ,,

There are two distinct types of malleable casting, fundamentally different as to microstructure yet having similar mechanical properties. The first is known as white-heart malleable and the second as black-heart malleable.

On account of the necessity for the castings being white in the first place, the irons which the malleable founder uses are selected from a range of hematite quality low in silicon, varying from grey to mottled to white. Such irons are of two kinds, one direct cast from the blast furnace, the other specially refined.

There is much diversity amongst different founders in the matter of cupola mixtures, and the white iron castings produced from different sources have been found to vary over a wide range, viz.: total carbon, 2.9 to 3.3; silicon, 0.4 to 0.8; sulphur, 0.15 to 0.35; manganese, 0.1 to 0.3; phosphorus, 0.05 to 0.10 per cent. It is possible to anneal successfully any iron falling within this range, given suitable annealing treatment, but different compositions require different annealing treatment. Malleable founders do not as a rule consider it practicable to vary their annealing practice to meet with changes in the composition of the white iron, and for simplicity of operation prefer to adhere to a standard practice. The aim in cupola working is, therefore, to commence with and thus produce a white iron of consistent chemical composition which is suited to the annealing practice. This is the only consideration which can be allowed to have any weight in determining cupola mixtures. The high shrinkage of white iron, which is about double that of grey iron, necessitates the use of heavy runners and large feeding heads in order to ensure sound solid castings, and the amount of scrap from this source is on the average about equal to the weight of the castings.

For producing small quantities of malleable iron the barrel or drum furnace is extensively used, especially where small quantities of malleable iron have to be quickly made. The loss due to oxidation can be kept within favourable limits by suitable direction of the flame

and careful fuel regulation. The usual capacity of these furnaces is from 10 cwt. to 1 ton. Often a cupola is used when production conditions permit.

Crucibles are also suitable for the production of malleable iron, having the advantage of great control over the analysis of the castings. There is a minimum loss or gain of the elements accompanying the iron. A small quantity of silicon is taken up from the crucible, which is of benefit to the casting. On the other hand, the fuel consumption is very high, so that the crucible process is uneconomical and fallen into partial disuse. Crucibles were among the first to be used for the production of malleable iron.

The electric furnace may also be used for melting malleable iron: the necessary temperatures are easily attained, the loss is favourable, and where the price of electricity is low it is also economical. However, a certain amount of care is necessary in using them.

As required, the molten metal is tapped into ladles and then cast into sand moulds. In the designing of malleable castings, as for those of other materials, care must be taken to avoid sharp changes of section, otherwise there is danger that cracks will develop.

Annealing Malleable Castings

Apart from suitable mixtures and correct pouring temperature, the essential factor in the production of malleable castings is the annealing. Thus when the castings are cool they are freed from the adhering sand in tumblers by using a shot blast. Then they are carefully packed in pots containing materials which will give off oxygen (iron ore, hammer scale, etc.). A good ore for this purpose should contain at least 80 per cent. of ferric

oxide with not more than 2 per cent. ferrous oxide, 12 per cent. silica, 1.5 per cent. lime, and 0.1 per cent. sulphur. In order to prevent too rapid oxidation, neutral substances, such as sand, are mixed with the ore. With intimate contact between the castings of white iron and the packing material the oxygen of the ferric oxide passes, during the annealing, into the outer surface of the white iron and there decomposes the iron carbide (Fe_3C). This process gradually goes on deeper into the inside of the casting. The carbon which had been combined with the iron thus becomes free and separates out in the amorphous form, the so-called "temper-carbon." Most of this temper-carbon is burnt to CO or CO_2 by the oxygen, the carbon content of the material being thus reduced. This separation of temper-carbon is the cause of the black core of the American black-heart malleable iron. The decomposition of the iron carbide continues with increasing temperature until only some 0.75 to 1 per cent. of the carbon remains in the combined form. Since the decomposition of the carbide proceeds very slowly towards the end, it is very difficult to determine the time required for its completion.

The annealing is either continued for eight days at a temperature just below the critical point (740° C.) or it is done for a few hours only at a very much higher temperature, in which case the castings are very slowly cooled in the region of the critical temperature. The first method gives the best castings but takes more time. The properties of the material produced by the second method of high temperature and short time of annealing are deficient in regard to strength, but hard spots due to segregation are softened, which is often very important. The American black-heart malleable iron is annealed for 72 hours at about 740° C.; the European, following

Réaumur, called tempered cast iron, is annealed for 120 hours at 820° C. To check the process, test pieces are placed in the annealing pots from the fracture of which it is possible to judge how far, *i.e.*, how deep, the process has gone. The operation of the furnace should be controlled by the use of recording pyrometers.

Black-Heart Malleable Iron

Black-heart castings as cast are white in fracture, but the composition of the white iron differs considerably from that used for white-heart, being low in sulphur, higher in silicon and manganese, and lower in total carbon. The higher silicon is associated with the lower total carbon, and vice versa.

The necessity for low sulphur and low total carbon rules out the cupola for melting purposes, and the air furnace is always used for melting black-heart. The metal has very similar casting properties to white-heart, the lower carbon being compensated by the higher silicon.

While the annealing furnaces, pans, and details of packing are the same for black-heart and white-heart malleable, the principles involved are different. Black-heart, by reason of its higher silicon content and its lower sulphur effectively balanced by manganese, is a metal which will graphitise much more readily than the white-heart metal. Graphitisation only is relied upon for malleablising black-heart, and the packing which surrounds the castings in the annealing pans is crushed slag or other non-oxidising material. No decarburisation takes place, and the function of the packing is merely to support the castings and to exclude air. The actual annealing temperature varies from 680° to 880° C. The

lower the temperature the longer the period required for annealing.

As a result of the annealing process the metal is completely graphitised, the amount of carbon remaining in the combined form being very small indeed. The amount of carbon removed by oxidation is negligible. Unlike white-heart, the structure is uniform throughout and the malleablising effect penetrates to the centre of the thickest section.

Black-heart malleable is more ductile than white-heart, the elongation and bend figures being generally higher, but the tensile is approximately the same.

The following figures are stipulated in B.S. 310: Ultimate tensile strength (minimum), 20 tons sq. in.; elongation in 2 in. (minimum), 7.5 per cent.; bend cold round 1-in. radius (minimum), 90 degrees.

The Light Metals

Aluminium and Magnesium.—The two light metals aluminium and magnesium and their alloys are used extensively when a high strength to weight ratio is required as in both automobile and aeronautical engineering design. Both metals may roughly be regarded as being white in colour, and for comparison the weights per cubic inch of the two light metals and a few others in common use are given:—

Magnesium	0·065 lb. per cubic inch.
Aluminium	0·098 ,, ,,
Duralumin	0·103 ,, ,,
Cast iron	0·26 ,, ,,
Steel, plain carbon	0·283 ,, ,,
Steel (hss)	0·32 ,, ,,
Copper	0·32 ,, ,,
Lead	0·41 ,, ,,

As with other metals, experience has shown that by alloying small quantities of other metals with the base metal, either aluminium or magnesium, under controlled conditions, a marked increase in the mechanical properties of the resultant alloy can be obtained, and often the metal becomes amenable to heat treatment.

It was in connection with the aluminium alloy duralumin that the phenomena now known as "age-hardening" was first observed. Thus when the alloy is heated to a given temperature and quenched, it is in a soft, ductile but unstable condition. Then with the passing of time the treated material hardens and becomes stronger, but loses its ductility, so that in roughly seven days the tensile strength has increased from, say, 10 tons to, say, 24 tons per square inch—this in marked contrast to pure aluminium and a number of other alloys which can only be given improved mechanical properties by cold work. The effects of the latter, with any subsequent heating, is wiped out.

By the process of development there are now a number of aluminium and magnesium alloys which require a duplex heating process in order to attain the maximum mechanical properties. The first is known as the "solution treatment" and consists of heating the metal, under controlled conditions, preferably in an air furnace, so that the constituents are taken into solution, and this is followed by a quench in cold water. At this stage the metal is quite soft and ductile. Now comes the "precipitation treatment," which is a low-temperature heating for several hours during which the excess of the constituents held in the solution by the rapid cooling is thrown out of, or precipitated from, the solution. In doing so, these small particles lead to a hardening of the material. It should be noted that the precipitation

treatment is somewhat akin to tempering carbon steel but with the opposite effect, for when carbon steel is tempered after the hardening quench it becomes softer, whereas when a suitable light metal alloy is taken through the combined solution and precipitation treatments the material becomes both harder and stronger.

When producing articles from the bar there are now available a number of free cutting alloys, and the possibility of using these should always be considered when the functional aspect of the component will permit.

The various light metal alloys may be obtained in the usual cast and wrought forms. It should be understood that any heat treatment of the alloys must be done under strict pyrometric control, using suitable and efficient equipment combined with skilled attention, otherwise much trouble in the form of scrap production can be expected. Hence when handling any of these alloys for the first time one should consult a person having the requisite skill and knowledge, or ask the suppliers for full information and then work to it, for it is cheaper, quicker, and less fraught with mental anxiety than attempting to find, unaided, the various characteristics associated with each alloy.

Zinc Base Alloys

The zinc base alloys are used in pressure die casting and the metals used are practically pure zinc. The number of alloys available is small and the composition is adjusted to give dimensional stability to the cast article.

Copper and Copper-Based Alloys

Copper is one of the most used metals in industry, either by itself or as a portion of an alloy. The material is red

in colour, has a fine grain size, and when in an annealed state it is exceedingly ductile. Due to its high conductivity it features in a wide range of electrical equipment; because of its resistance to many forms of corrosion it is chosen for a wide range of chemical and food processing plant, whilst its high heat-conductive capacity makes the metal valuable in a number of mechanical engineering designs. When articles have to be produced from the bar, one may choose a free cutting alloy when this is permissible.

Phosphor Bronze.—Phosphor bronze is a copper tin alloy containing a small percentage of phosphorus and B.S. 384, has a composition of 94 per cent. copper, approximately 6 per cent. tin, and 0.1 per cent. phosphorus. In the wrought form phosphor bronze is used in the electrical industry for contact pins and springs. When cast or in the wrought state phosphor bronze is widely used for bearings, valve bodies, gears, and similar parts. Under a number of conditions it possesses a good resistance to corrosion.

Gun-Metal.—The name of this alloy at once indicates its former use, but to-day it is chosen for bearings, valve parts, and gears. One standard, B.S. 382, gives the composition as 88 per cent. copper, 10 per cent. tin, and 2 per cent. zinc.

Aluminium Bronze.—This alloy is one of the high tensile groups of non-ferrous metals, and the composition given by D.T.D. 135 is copper 89 per cent., aluminium 10 per cent., nickel 1 per cent.

The Brasses.—The general run of brasses, grouped according to the copper content, may be listed under the following headings:—

(*a*) The gilding metals or red brasses (B.S. 711), which have a copper content of 80 per cent. or more, the remainder being zinc. The alloy is ductile and works well under the press, when drawing as for tubes, and spinning.

(*b*) Cartridge metal, which is a brass having 70 per cent. copper and 30 per cent. zinc. This alloy (B.S. 267) is the chief cold working brass and, as its name implies, it is used extensively in the production of cartridge cases and similar deep drawn articles.

(*c*) The 65-35 mixture to B.S. 266. The cold working properties of this alloy are not quite so good as those of the 70-30 mixture, but when economic considerations enter into the question this metal is often used in place of the cartridge metal for deep drawn articles.

(*d*) Basis brass (B.S. 265) has a copper content of 63 per cent. and 37 per cent. of zinc. This metal has the lowest copper content of any of the cold working brasses. It can be used for deep drawn articles, but the margin of safety is very small, and unless care is exercised at all stages the scrap percentage may be very high.

(*e*) The high tensile brasses, often termed the manganese bronzes (B.S. 208/1 to 5), have a copper content of, say, 58 per cent. with the zinc being between 35 per cent. plus other elements which together give a strong metal.

(*f*) A brass (B.S. 218) for hot pressing, and the general composition is copper, 58 per cent.; zinc, 40 per cent.; and lead, say, 2 per cent. The low copper, high zinc, and lead addition give the alloy a high degree of plasticity when at a temperature of around 600° to 750° C.

(g) When articles are to be made from the bar on capstan and automatic lathes, the alloy B.S. 249 having a copper content of 58 per cent.; zinc, 39 per cent.; and lead 3 per cent. is chosen. The lead addition gives a free cutting alloy which can be cut at a high speed.

Leaded Alloys.—In addition to the above copper-based alloys there are a number of others to which lead has been added to give plasticity to the metal so that they form excellent bearing metals. The lead content varies over a wide range from, say, 5 to 25 per cent., and is added to the phosphor bronzes and gun-metals.

Nickel and other Non-Ferrous Nickel-Containing Alloys

Nickel, a silvery white metal, is used by itself when a high resistance to corrosion is desired. It is also an important alloying element in both the ferrous and non-ferrous spheres.

Cupro-Nickel.—A range of copper nickel alloys, known as the cupro-nickels, have a copper content varying from 95 to, say, 67 per cent. copper and 5 to 33 per cent. nickel, and this includes the well-known alloy, monel metal.

Nickel Silvers.—The nickel silvers are a mixture of copper, zinc, and nickel, the content of the latter varying from 10 to 30 per cent. These alloys are covered by B.S. 790 and are used when resistance to corrosion is desired, as with domestic hollow-ware and springs.

Castings in General

Sound castings depend upon several factors, such as skilful design, a suitable mixture, correct melting, good moulds, and foundry technique. Now one of the troubles of the machine shop is that a defective casting may only show up its defects after much time has been spent machining the article, whilst those with hard spots make machining difficult and may ruin a costly tool.

Successful castings largely depend upon their being well designed, not only in respect of their actual purpose but in order that the best use of both labour and material may be made in their production. Poor design may increase the cost of production, and may even result in a casting breaking up under its own cooling stresses. The designer must consider the casting from the foundry point of view. Thus it is necessary to estimate the load and to provide a suitable section; ensure that the appearance is satisfactory without detracting from the strength; equally important is designing the casting so as to simplify the work of moulding. This renders it necessary to decide upon the general contour of the article and the way the pattern can be best withdrawn from the sand. Judicious use of tapers, for instance, may often obviate disturbance of the mould when the pattern is removed from the sand and so add to the accuracy of the finished article besides facilitating production. Then, again, there is the matter of weight. It is often cheaper and easier to make a hollow casting than it is to make a solid one, and while it is desirable to reduce machining as much as possible, cutting the thickness of parts too fine, especially those parts which have to resist pressure, may result in weakness on account of those parts being liable to run up weakest in the casting. Careful attention is also

required where a change of thickness is considered desirable. A well-designed hollow casting of practically equal thickness usually gives the best results. Where thick and thin parts are combined in the same casting there is considerable risk of shrinkage fractures, and changes of thickness should be introduced sparingly, and then only with the transition made in generous curves. It is hardly necessary to add, too, that all internal angles should be well filleted, even if machining operations call for it to be removed, in addition to which well-rounded corners add to appearances. In respect of machining allowances, while weight of metal and labour in machining can be reduced by cutting this down to a fine limit, yet it is likely to prove false economy. Surface defects, which do not as a rule detract from the value of the casting, can generally be cleaned up if $\frac{1}{4}$ in. or even $\frac{3}{8}$ in. of metal is left, whereas with a bare $\frac{1}{8}$ in. the surface may be very unsatisfactory.

Patterns

Poor patterns are responsible for more bad castings than one untrained to foundry work is apt to realise, a fact which is fully appreciated in most foundries. Making up of moulds is unsatisfactory in that the time is excessive, and the necessity for constant patching arises. A smooth surface on the faces of the pattern, too, is very important. While a skilled moulder can deal with corners and fillets, more time is required than is the case with a well-made pattern. Machined wood fillets can be quickly sprigged into position, while if the radius is fairly large, say 3 to 4 in., the pattern-maker can cut and fix sectional pieces and sprig them on the pattern with spaces between. These spaces can then be filled with sand by the moulder, who thus obtains a full round in the mould. The proper

formation of fillets on the pattern is really quite important. In green sand moulding, for instance, it is much better not to touch the face of the mould after withdrawal of the pattern. True, corners can be patched up, but a much better surface is obtained from sand that has been rammed against the pattern, and patched parts are always noticeable. While appearance may, as a rule, be regarded as a secondary consideration, yet one cannot associate the rough-and-ready look of some castings, however sound they may be, with best engineering practice. Often fillets which form the transition between thick and thin sections of a casting must be finished by the pattern-maker on account of the difference in radius necessary between that on the pattern and that on the core box. A bad pattern runs up foundry costs and causes discrepancy of weight between castings, though it may operate to the advantage of the foundry in respect of the extra metal used. The use of standard patterns giving a rough outline of the shape required, and to which new branches may be fitted as necessary, is not to be advocated as really good work cannot be done with them. Good pattern-making admittedly costs money, but it is an economic proposition in that it cheapens the cost of moulding and ensures better castings.

Tests

Some specifications still show an extraordinary reliance upon test bars on the part of those responsible for drawing them up. The test bar and the results it gives are assumed to indicate the quality of the metal as a whole. As a matter of fact, only quite small and simple castings are in any way uniform throughout their mass. A sample, when cut from an individual casting, cannot be regarded as representative of it as a whole. At best the test bar

can only be used as a means for ascertaining that the metal from which the casting has been poured gives results up to a certain standard of quality when cooled under standard conditions. This certainly affords some reliable information as to the quality of the metal. It is important that the designer should know where the maximum strength of the casting is needed and what the general strength should be, and thereby be able to estimate pretty closely the points at which the bars should be taken off. This will ensure their being reasonably representative of the strength and quality of the metal being dealt with if it is borne in mind that the strength of a test bar usually exceeds that of the metal in the body of the casting. The usual practice is to have 1 in. square bars taken off selected points, but bearing in mind that the skin of a casting has a somewhat greater strength than the body of the metal, it would prove more reliable to cast them 1¼ in. square and to machine them to size for testing. Yet cast iron must, of necessity, always be regarded as more or less unreliable and provision made accordingly. Parts which have cooled rapidly are usually harder and stronger than those which have cooled more slowly, while porosity may be present in parts not indicated by the test bars.

Porosity is, in fact, the great source of weakness in castings, and its presence can only be detected on determining the density of the casting by weighing it in air and water if this is possible. A low density is a sure sign that unsoundness exists, as it indicates the presence of porosity which is due to the liberation of gas. It is a troublesome matter for the founder to deal with, though it may to some extent be eliminated by good feeder heads, uniform cooling, and very slow solidification.

In the light of modern investigations the usual tests

applied to metals must be regarded as more or less unreliable, and for accurate results the casting itself should be subject to tests as encountered in service.

It is necessary to appreciate the fact that in the great majority of materials those parts of a casting which have a thin section, and therefore cool more rapidly in the mould, are harder and stronger than parts having a thick section which undergo more gradual solidification. Further, unless a casting is skilfully designed and very carefully made, there is a risk that, owing to "drawing," one part of a casting may become sound and strong at the expense of a neighbouring part, which is left porous and weak. There is also the fact that, owing to variations of detail in melting or casting temperatures and other factors, the properties of one casting may differ appreciably from those of another of the same type and series.

In view of these facts it must be realised that even if a sample is cut from one of a series of similar castings, or even if an entire casting could be tested, the test still remains that of a sample, and to that extent does not differ appreciably from the testing of a specially cast sample, provided that the latter has a cross-section which may be regarded as reasonably representative of that of the casting itself.

When cast iron is welded with a steel or iron electrode the fusion point is extremely hard and non-machinable and the surface can only be finished by grinding. For this reason monel metal electrodes were introduced, and their use is now being extended, experience having shown that, with proper welding apparatus, they give a surface capable of being machined as readily as the parent metal.

The monel metal rods supplied for the metallic arc welding of cast iron are coated with a special flux which protects the weld metal from oxidation and fluxes off any

oxides which may be formed. Bare monel metal wire is supplied for oxy-acetylene welding, and refined powdered borax should be used as a flux. With gas welding it is necessary to preheat the casting. Where possible, electric welding is recommended.

Some Common Casting Faults

These usually take the form of blow-holes, sponginess, scabbiness, and sand-holes. Blow-holes are a common defect and they may not be apparent on the outside; on the other hand they may occur in locations where they would not do any particular harm, and their existence does not necessarily imply that a casting should be rejected. Sponginess, while due in many cases to an improper mixture of iron, may also be due to abnormal thickness at some point of the casting, and if such thickness is absolutely necessary the founder must arrange his casting methods accordingly in the shape of a riser placed directly over the heavy sections. Another defect to be found in abnormally thick portions of a casting is shrink-holes, which can also be prevented in the same way as sponginess; at the same time these heavy sections should be avoided if at all possible. Scabbiness, the term applied to those rough depressions on the surface of a casting, is due, as a rule, to improper gating; at the same time the design may have rendered this impossible, and the existence of sections which demand sharp fillets or thin tongues of sand projecting into the mould are both conducive to scabbiness, which is the result of the metal scouring them away and depositing them elsewhere in the form of scabs. The same conditions result in sand-holes which may be large enough to render the casting weak or useless, while if small they will undoubtedly give

trouble in machining. In looking over a casting for faults, a close examination should first be made of the skin of the metal, and if blow-holes are revealed or the metal is obviously spongy, or if there is a fracture at the joining of a thick and thin section, a further examination will be necessary. If the metal appears to be sound, it is then necessary to test for thickness, which, in the case of intricate cores, is often difficult. Should a discrepancy exist between the thickness indicated on the drawing and that of the casting, the pattern and casting should first be compared, as either the patterns or core boxes may be in error, and the swelling of a core box or the shrinking of a pattern will make quite an appreciable difference if the metal is in any way thin. Small bosses, too, are sometimes omitted by the pattern-maker and sometimes by the moulder, while loose pieces do at times get rammed out of position in the mould.

Contraction Stress

While the foregoing faults may or may not have to be regarded seriously, having in view the purpose of the casting and other practical considerations, contraction stress is a species of hidden fault which may cause the sudden and dangerous failure of a casting in use. Its avoidance largely rests with the designer. A good example is a cast-iron wheel. The thin rim cooling and setting prior to the comparatively heavy boss puts the arms in tension, rendering them liable to crack at their weakest section. Hence the familiar curved arms given to wheels which enables them to adjust themselves to this pull. Then, again, take the ordinary box form of casting. There is a contraction pull towards the centre of each of the sides, tending to produce rupture at the

corners. Hence the necessity for rounding corners so as to reduce the concentration of the stress, while, if necessary, a curve may have to be substituted for the corner. Many other examples could be given, but those quoted serve to show that with a bad design a moulder may produce a good-looking casting, but it may also be a dangerous one. Contraction stress may exist, due to sudden change of form or difference in sectional area of parts of a casting, and it is liable to be intensified if cooling is rapid. The only safe remedy is the adoption of sound principles of design.

CHAPTER VII

WROUGHT IRON AND STEEL

Wrought Iron

In order to produce wrought iron of good quality, pig iron from the blast furnace is first put through a refining process, the object of which is to convert or abstract the whole of the uncombined carbon. This object is accomplished by melting the metal and forcing a blast of air on to the surface of the molten metal and thereby oxidising the carbon and producing what is known as white iron.

The next process is to convert the white iron into wrought iron. To do this the slabs of white iron are broken and taken to the puddling furnace. The furnace, shown in Fig. 161, is made up of two principal parts: A, the fireplace; and B, the hearth. The fireplace and hearth are provided with a low, arched roof sloping down to the flues at the base of the chimney-stack. The chimney-stack is carried to a height of about 40 ft., and is fitted at the top with a damper, which is operated by means of a lever; this allows the draught to be regulated during the melting process. The fireplace is built of firebrick braced together with cast-iron plates. The hearth tapers towards each end, and is about 6 ft. by 3 ft. 6 in.; the base of the hearth is constructed of iron plates arranged to allow air to circulate beneath them.

Puddling

The hearth of the furnace is lined with oxide of iron and tap cinder, and the charge consists of about 4 cwt. of white iron; this amount requires about half an hour to become partly melted, and to form a pasty mass. When it is in this state it is thoroughly rabbled with the tap cinder in order to bring every part under the oxidising influence of the oxide of iron; the carbon then combines with the oxygen and passes off as CO_2.

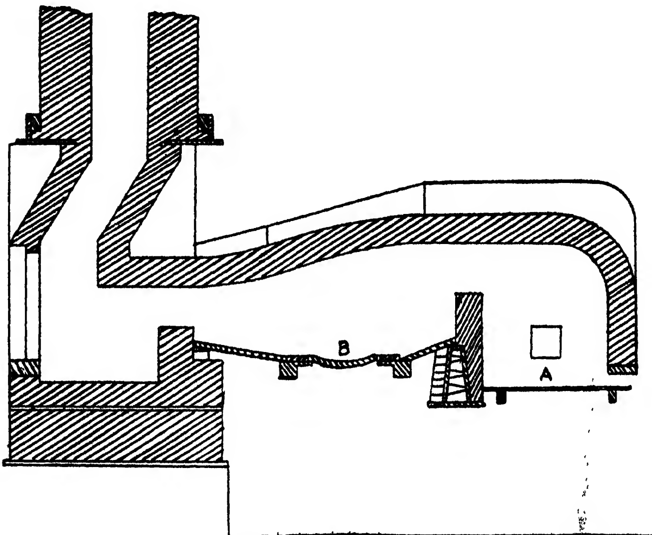


FIG. 161.—Section through Puddling Furnace.

At this stage of the process jets of flames, known as puddler's candles, are formed, the slag begins to drop, and

particles of malleable iron float on the surface, forming a spongy mass. These particles are worked together by the puddler and made into balls. The balls are taken to the shingling hammer and then hammered, so that the slag is squeezed out and the iron welded together, forming what is known as blooms. To improve the quality of the iron the blooms are reheated, piled four high, and welded into billets, and then again reheated and rolled into the desired section.

Since the introduction of mild or low carbon steel on a large scale, the importance of wrought iron has steadily decreased. This is due to high costs associated with the process and the entrapped slag. Hence to-day, that is, halfway through the twentieth century, wrought iron is only chosen when its properties justify the higher costs.

Blister Steel

The production of blister steel by the cementation process is the most important preliminary process employed in the manufacture of crucible cast steel. To produce blister steel by the cementation process, best selected bars of wrought iron are placed in a cementation furnace surrounded and packed in with charcoal, the furnace fire is lit, and in two days the conversion of the iron begins. A temperature sufficient to keep the bars at a blood-red heat is maintained for about nine days, the actual time being determined by the percentage of carbon required in the iron, and which ranges between 0.6 and 1.6 per cent.

At the end of the heating period the fire is withdrawn and the bars taken out, when they are found to be covered with blisters. The bars are broken into short pieces, piled, reheated, treated with a flux of borax and sand, and then

welded together and drawn into bars; it is then called single shear steel.

When a better quality steel is required, the single shear bars are broken into short lengths, selected for fracture, and then piled, reheated, welded, and drawn, and the product is then called double shear steel.

With the development of the electric furnace the production of blister steel has practically ceased, so that to-day, 1950, the process may be regarded as one of a past age. Hence no steel truly answering to the term "double shear" is now made, although the old trade term is still used.

The Cementation Furnace

A transverse section of a cementation furnace is seen in Fig. 162. A shows the converting pots, B the firegrate, C the flues for distributing the heat, D the chimneys which communicate with the stack E, F (not shown) the manhole for introducing or withdrawing the charge, and H the charging hole.

Crucible Steel

Cast steel, or what is sometimes called tool steel, was at one time made from blister steel by cutting the bars into small pieces and melting them in a fireclay crucible, adding the necessary amount of carbon in the form of ferro-manganese.

Another method of making cast steel, or alloy steel, is to take small pieces of best Swedish bar iron and melt it in air-tight crucibles, adding oxide of manganese, charcoal, and any other elements required. The steel is run into iron moulds, forming ingots which are hammered into bars or rolled into sectional shapes.

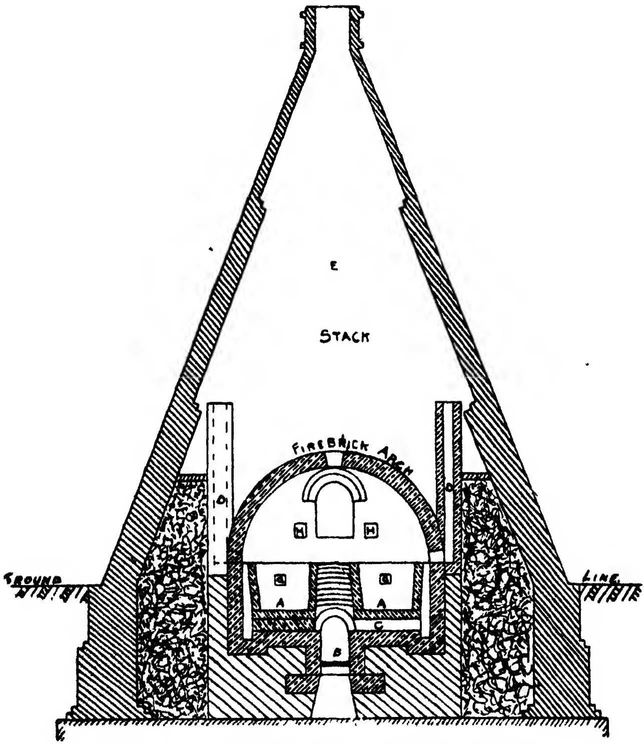


FIG. 162.—Section of a Cementation Furnace.

Modern metallurgical practice has rendered the crucible process of steel making practically obsolete. Hence it is rare in 1950 to find that the high-grade cutting steels, either plain carbon or alloy, are produced in the old type of crucible furnace. Bulk of this class of steel is now produced in the electric furnace under close metallurgical laboratory control.

The Crucible Furnace

A section of a crucible steel melting furnace is shown in Fig. 163. This consists of a melting pit A, in which can be

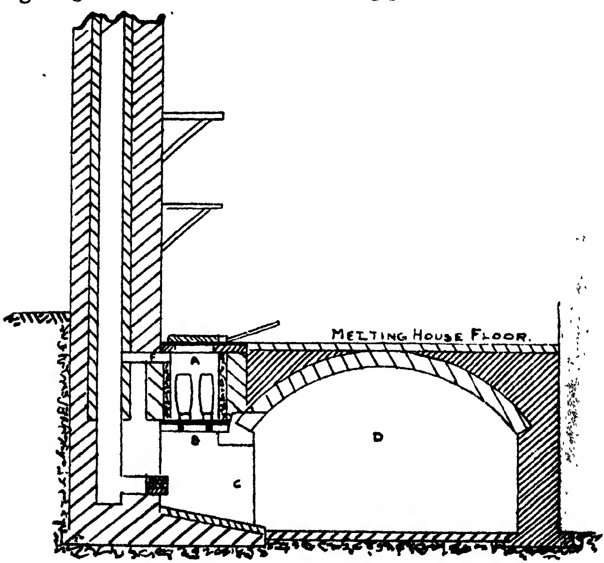


FIG. 163.—Crucible Steel Melting Furnace.

placed two crucibles, an ashpit C, firebars B, and a cellar D. The melting pit is a rectangular chamber about 3 ft. deep and 2 ft. square, lined with firebrick and rammed ganister. The top of the furnace is on a level with the floor of the melting house, and is kept covered with a square firebrick slab. The grate bars and ashpit are below floor level, and an arched cellar enables the workmen to reach the ashpit when necessary. The melting holes are connected to the stack by means of a flue, and about six furnaces are carried into one stack.

The crucibles are made in cast-iron moulds of fireclay and plumbago, the former being generally preferred. The crucibles have to be carefully dried. They hold a charge of about 56 lbs. Three meltings in one day are generally taken, the charge being reduced at each successive charge in order that the surface of the molten metal shall be at a different level in the pot.

Gas fixed regenerative furnaces for making crucible steel are used to a limited extent, and they are claimed to be very economical and give excellent results.

Open-Hearth Steel

Several methods of producing open-hearth steel are in vogue, the general principle being that a certain quantity of pig iron is melted in a reverberatory furnace and red hematite added to oxidise the carbon, silicon, and manganese. Carbon is then added in the form of spiegeleisen and ferro-manganese. It is somewhat similar to the process of puddling wrought iron, only on a larger scale. The furnaces have a capacity of 30 to 50 tons, and are heated by gas made from bituminous coal. The air and gas are passed through regenerative chambers before being allowed

to enter the combustion chamber, and are heated to a temperature of about 1,200° F. This preheating of the air and gas allows of an extremely high temperature being maintained in the furnace, and thereby keeps the metal in a liquid state.

The charge of molten metal has mixed with it red

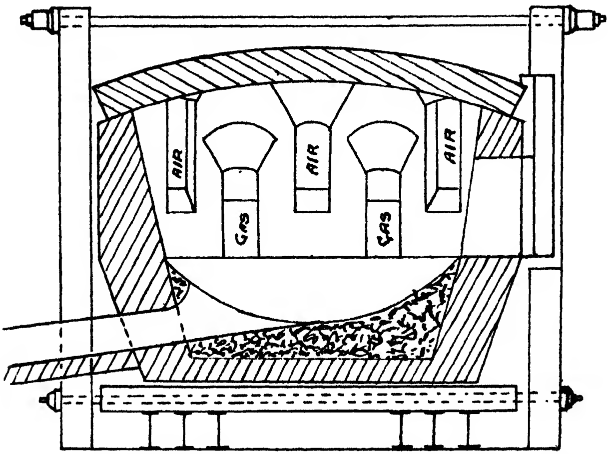


Fig. 164.—Siemens Open-Hearth Furnace.

hematite ore or other oxides, which, owing to the chemical reactions, keep the molten iron in a continuous state of agitation. In the open-hearth process it is usual to make use of scrap wrought iron or scrap steel, because the high temperatures obtained by the regenerative furnace allows of their being brought to a molten state. If the scrap contains too much phosphorus, then burnt lime is added to the charge; and when lime is used in order to keep the slag basic, the process is called the "basic process."

To melt a 30-ton charge of open hearth steel takes about five hours.

A section of a Siemens open-hearth furnace is shown in Fig. 164. The body of the furnace is built of mild steel plates, lined internally with firebricks. The bottom of the furnace is usually made of cast-iron plates. The gas enters the hearth of the furnace from the regenerators through two openings or ports, and the air through three, and these are arranged side by side. It is of great importance that the combustion of the gas in the furnace hearth should be as perfect as possible, for not only will the calorific efficiency of the furnace as a heating machine depend upon this, but also the calorific intensity of the flame.

Bessemer Steel

Another method of steel manufacture uses what is known as the Bessemer converter (see Fig. 165). In this process

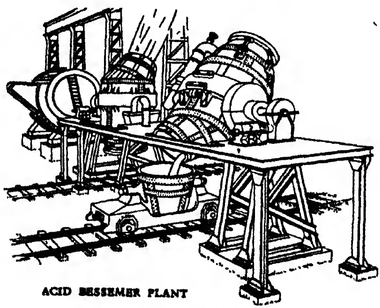


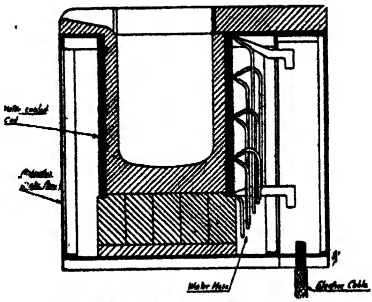
FIG. 165.

the molten iron is taken from the blast furnace and placed

in the converter. Then a blast of air is driven through the molten mass so as to burn out the impurities. Afterwards suitable additions are made to give the desired analysis to the metal.

Electric Furnace

The general tendency to-day is to use the electric furnace for steel production. With this process no impurities are



ELECTRIC HIGH FREQUENCY FURNACE

FIG. 166.

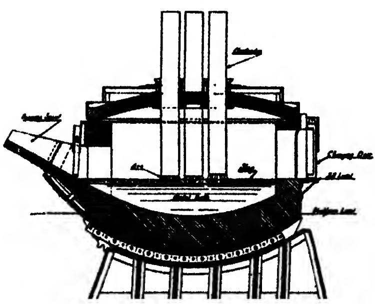


FIG. 167.

carried from the fuel into the metal. In modern metallurgical practice the electric furnace (see Figs. 166 and 167) can be used for direct reduction of the raw materials or for refining only.

FIG. 168.—An Electric Furnace as Used in a Steel Foundry. The pouring of a charge in the foundry of F. H. Lloyd & Co. Ltd., Staffordshire.
(*By courtesy of Messrs Birlec Ltd., Birmingham.*)

The Duplex Process

In order to achieve the most economical results in steel manufacture the Bessemer converter or the open-hearth furnace is used in conjunction with the electric furnace.

The initial melting is done in either of the former and thus removing the bulk of impurities from the charge, and at this stage the molten metal is run into the electric furnace for the final refining stage and the addition of such alloys as are required. In this way the strong points of each process is used.

General Classification

A very rough classification of the types of steel now available to the engineer is somewhat on the following basis:—

Low Carbon Steel.—The plain low carbon steels may be taken as having a carbon content varying from, say, 0.05 to 0.25 per cent. carbon. This grade of material will not respond to any heat treatment designed to give greatly increased hardness through the mass. Nevertheless this range of steel is used in a wide range of constructional designs where moderate strength and toughness is desirable. Since its introduction it has steadily pushed out the use of wrought iron for many purposes.

Medium Carbon Steel.—The medium carbon steel has between, say, 0.25 and 0.65 per cent. carbon. In the higher carbon range the material does partially respond to the hardening quench. This grade of steel is chosen when the combination of toughness and strength 35 to 45 tons per square inch is required.

High Carbon Steels.—The plain high carbon steels may be said to have a carbon content ranging from, say, 0.65 to 1.4 per cent. In the higher range of carbon the material becomes very hard following heating and quenching above, say, 780° C. This grade of material

is used for all types of cutting tools; that in the lower carbon range for tools which have to withstand shock such as a cold chisel, and in the higher carbon range for tools and instruments such as lathe tools, taps, razors, and surgical instruments which must take a keen cutting edge.

Steels having a Low Alloy Content.—For purposes of grouping, the steels coming under this category may be taken as having an alloy content of up to 5 per cent. Upon this basis they include, first, the steels as given above under the heading of low carbon steels. In this manner one gets a low carbon low alloy steel, and the group includes the usual alloy case-hardening steels. The second group of low alloy steels is that listed as having a medium carbon content, and therefore one gets a low alloy medium carbon group which comprises the wide range of constructional steels used in the heat-treated condition. The tensile strength varies from, say, 45 to 100 tons per square inch. Within this grouping are a number of steels as used in the production of much tooling equipment. Then comes the high carbon low alloy steels as are used for many types of cutting and other tools.

Steels having a Medium Alloy Content.—The steels having an alloy content between, say, 5 to 13 per cent. may be regarded as coming within the medium alloy grouping. Then further sub-dividing on the basis of carbon content as has been done for the low alloy group one gets: (1) low carbon medium alloy steels, (2) medium carbon medium alloy steels, (3) high carbon medium alloy steels. The steels coming within this group of medium alloy content are used for constructional purposes and many types of tooling equipment. In each case the type of steel must be related to the conditions under which the component has to operate.

Steels having a High Alloy Content.—When the alloy content of a steel is over 13 per cent. it may be regarded as a high alloy steel. Within this grouping comes the high-speed steels, the stainless and heat-resisting steels, also many of those brought out to meet specific service conditions. The carbon content of these steels varies over a wide range and covers the low, medium, and high carbon groups, and is adjusted to meet the known operating conditions, also manufacturing.

In order to be classed as an alloying element the material must be used in amounts over that found in the normal plain carbon steels. Upon this basis the use of manganese around 1.5 per cent., as in B.S. 970, En 14B, brings the steel within the classification of a low alloy steel, as does the increase of silicon to, say, 4.5 per cent., or the increase of manganese and sulphur to produce a free-cutting mild steel.

Alloying Elements

At the present time, 1950, the alloying elements used in steel manufacture are given below.

Copper.—Copper is added to the low-carbon constructional types of steel to produce a material which better resists the effects of atmospheric corrosion.

Cobalt.—Cobalt is used chiefly as an alloy in the high-speed cutting steels where its high "red hardness" value is required to maintain a sharp cutting edge even when operating at a high temperature. It is used in conjunction with other alloys such as tungsten.

Chromium.—The addition of chromium to steel is to impart one or more characteristics to the material. In the low alloy grouping it reduces the effect of "mass" and produces a wear-resisting material. In the higher alloy

categories it is used because of its heat or corrosion resisting characteristics. Chromium may be used as the chief alloying element or in conjunction with nickel, molybdenum, tungsten, and cobalt.

Manganese.—Manganese is used as an alloying element to give the carbon manganese steels akin to B.S. 970, En 14B, or to form the austenitic manganese steel which has a manganese content of 11 to 14 per cent. When correctly treated the high manganese alloy work hardens very quickly, hence takes on a hard wear-resisting surface supported by a very tough core.

Molybdenum.—As an alloying element, molybdenum has the tendency to give an even structure throughout the mass and has a high resistance to softening by heat. For this reason it is used in the production of the molybdenum high-speed steels. It is used in small quantities in the nickel-chromium steels to prevent "temper brittleness," or in the stainless steels to avoid "weld decay." Molybdenum may be used by itself or in conjunction with other alloying elements.

Nickel.—Nickel is extensively used in a number of alloy steels to improve the tensile strength, wear-resisting properties, heat and corrosion resistance, and response to heat treatment. In the group of constructional steels the nickel content is generally under 5 per cent.; but for the heat and corrosion resisting types its content is much higher. Nickel may be used as the only alloying element or in combination with other elements such as chromium and molybdenum.. When nickel is present in sufficient quantity, the material has the tendency to work-harden rapidly,. and this characteristic permits the use of nickel steel for chisels, as demonstrated by Sir Henry Fowler who, after testing many types of steel, finally adopted a 3½ per cent. nickel steel with 0.4 per cent. carbon, and

up to 0.6 per cent. manganese, with which most excellent results were obtained in the shops of the London Midland and Scottish Railway. It was found that the performance of chisels in this nickel steel is greatly superior to that of the usual carbon steel chisels in the much longer life obtained before the edge is done up and requires re-forging.

The extent of the improvement will be appreciated from the fact that over a period of twelve months the number of chisels used was reduced from 18 to 1.2 for each man. The fact that the heat treatment required is a simple heating and quenching, without necessity for tempering, and also that when dulled the edge of the chisel can be brought into condition again by the simple expedient of filing also, of course, greatly assists to this end.

The use of nickel steel has been extended to many other tools, such as cold setts and boilermakers' tools.

Tungsten.—Tungsten is used to refine the grain size and, when in sufficient quantity, to improve the "red hardness" value of the material as is required with metal-cutting tools and various grades of hot working equipment. In the majority of the high-speed steels tungsten is the chief alloying element, and has been used in exhaust valves as fitted to internal combustion engines.

Vanadium.—This alloying element is chiefly used in the high-speed steels and gives a very hard wear-resisting edge that will retain its cutting efficiency for a long period.

Steel Castings

The general trend in metallurgical practice for the production of the wrought steels has had its impact upon steel foundry practice. To produce good, sound castings in low and medium carbon steels is not an easy operation, and the addition of the above-mentioned alloying elements

has tended towards a stronger and sounder metal. The general effect of each of the alloying elements upon the resultant metal has been given above, hence is not repeated.

Other Materials

In the workshop one will encounter stellite or the cemented carbides for cutting tools, the whole range of the plastic moulding compounds both thermosetting and thermoplastic, also the various grades of timber, but space considerations prevent these from being discussed.

Seasoning

This process consists in permitting roughly machined castings to achieve freedom from distortion by being placed for a long period to the ebb and flow of the climatic conditions. It may be likened to a low-temperature process in that the castings are exposed to the heat of the summer and frost of the winter, the range of temperature being, say, 80° C.

Precautions

With all heating processes one should take steps to avoid scaling. Thus one method of annealing is to pack the steel in a cast-iron box containing some material, such as powdered charcoal, charred bone, charred leather, slaked lime, sand, fireclay, etc. The box and its contents are then slowly heated in a furnace to the proper temperature for a length of time depending upon the cross-section. After heating, the box and its contents should be allowed to cool at a slow rate, preferably in the furnace, so as to prevent any hardening. It is wise, when annealing, normalising, or hardening, to exclude the air as completely as possible from the furnace and thus prevent the outside of the article from being oxidised.

At all times full use should be made of pyrometric control, whilst the maker's suggestions as to the best treatment should, failing well-proved experimental data to the contrary, always be followed.

Furnaces

Whether an industrial furnace is fired by coal, gas, oil, or electricity is a matter of individual choice, but modern workshop practice favours rather the gas, oil, or electric furnace.

Nearly all the metallurgical trades use furnaces of some kind, apart from the smelting industries, where, of course, the furnace equipment constitutes the principal part of the plant, and may be fired according to individual requirements and ideas. Even in steelworks of considerable size the value of gas and electricity is fully appreciated, while with small installations where annealing, reheating, case-hardening, tube-welding, normalising, and similar processes have to be carried out, gas and electricity are without doubt very important means of heating. Owing to its low cost producer gas provides cheap, clean, easily controlled heat for the various classes of work mentioned, as does the oil furnace. In certain districts, notably the midlands, manufacturers have the advantage of a public supply of both producer and town gas, which itself is sufficient inducement to use gas furnaces. Even when a gas producer forms part of the works equipment, the saving in fuel and ease of operation over a coal-fired furnace soon pays for its cost. As regards ease of operation and temperature control, both the gas and oil furnaces are vastly superior to the coal-fired furnace, but ignoring costs, an electric furnace gives very close control.

It might not at first be apparent why this should be so. It is mainly a matter of the perpetual enemy of efficient combustion, excess air, and it is heating this excess air to the temperature at which the gases leave the furnace that runs away with the fuel. When gas is used, little excess air is required, and the quantity can be so adjusted that there is actually surplus of gas in the furnace, thus giving either a reducing or a slightly oxidising flame. Apart from these advantages, the modern electric, gas, or oil fired furnace is designed with the object of keeping and utilising in the furnace itself the maximum

amount of heat generated. The products of combustion passing from the hearth are at high temperature, and in a properly designed furnace the greater part of the heat is extracted before the hot gases are discharged into the atmosphere, so conserving the heat in the furnace itself. Moreover, the standby losses are small, because after the gas is shut off very little fuel is required to keep the producer in a condition to be immediately restarted.

So far as the gas producers themselves are concerned, these are all more or less of a similar type, working on the Siemens pressure principle, which involves the passing of air and steam through a bed of incandescent fuel. Large batteries of producers are now almost invariably equipped with automatic charging, poking, and ashing gear, though for the average run of work the more simple hand-fired producer of the Dowson type satisfies most requirements.

When temperatures up to 1,400° C. are required, the recuperative gas-fired furnace is relatively cheap to install. It calls for little attention because there is no reversal of the direction of the flame, and once the furnace has been lit and brought up to the required temperature all that has to be done is to regulate the supply of gas and air and the chimney damper. An essential condition is rapid combustion, which calls for an intimate mixing of the gas and air. Fig. 169 shows how this is effected by Dowson's "Weardale" burner, where the gas is injected from the gas chamber through the nozzle, aspirating hot air from the hot-air chamber, the furnace being designed for firing from the crown. The flame spreads over a definite area of the hearth, so that a number of burners can be arranged in such a manner that the flame covers the whole hearth area. If the air is heated to 700° C. there is no difficulty in maintaining 1,250° C. in the

furnace with natural draft, though for higher temperatures it is economical to have the air under slight pressure.

Below the furnace the air which passes to the chamber is heated by recuperators from the hot waste products of combustion, these recuperators consisting of rectangular passages formed of muffle bricks with alternate air and

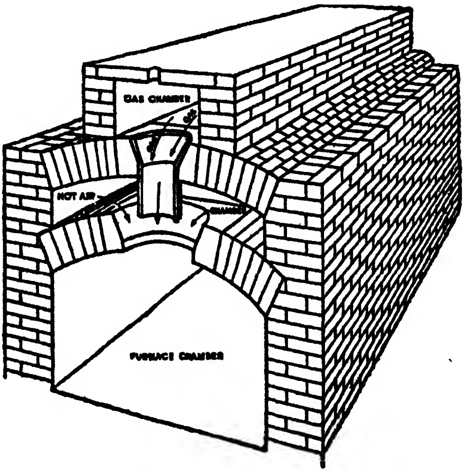


Fig. 169.—Dowson's "Weardale" Furnace

gas passages, the glazing of the bricks by the heat preventing leakage in working.

For dealing with a large number of pieces of metal of approximately the same size, it is usual to arrange for the ingots or billets to be laid on a table and pushed into the furnace by hydraulic gear and taken through at a regular speed, the billets being carried on water-cooled rails or skid bars. The gas is for preference fed from the top, as this leaves the sides and ends of the furnace free

for the withdrawal of material. The furnace is so designed that the material enters at the cool end and passes down to the hottest zone, an important matter with certain grades of steel which must not be fed directly into full heat.

For large outputs, an annealing furnace may have to be specially designed, though the continuous bogie type of furnace meets a good many average conditions. The general form of this type of furnace is shown in Fig. 170,

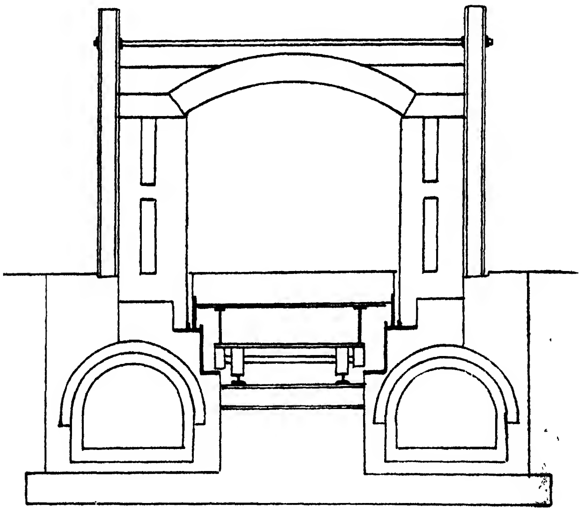


FIG. 170.—Annealing Furnace.

and there are three stages—the heating up portion, where the pots are rapidly heated up by the waste gases; the annealing portion, which is the firing space; and the cooling chamber. There is no recuperator, the air being heated in the side-wall passages indicated, while the burners are placed at the sides and bottom, so arranged

that the products of combustion will not impinge directly on the pots. As a general rule seven bogies are used, two heating up, two cooling down, and three annealing, and the particular design shown calls for the minimum of foundation work, an important matter on bad ground. For small outputs the single bogie furnace is a good proposition. While not so economical as the continuous type owing to the alternate heating and cooling and the loss of heat consequent on the withdrawal of the bogie, it provides even heating and perfect regulation of temperature, and if the waste products are used to heat the air for combustion, the greater losses, as compared with the continuous furnace, are due only to the cooling down of the furnace to a suitable temperature for withdrawing the pots.

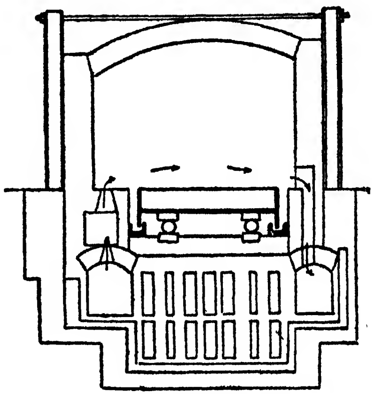


FIG. 171.—Bogie-Type Furnace.

The general lay-out of this class of furnace is shown in Fig. 171, the burners being placed at one side and the products of combustion drawn off at the other, the flame passing completely round the pots. The bogie, it may be noted, runs on a ball race and has a sand seal to prevent the ingress of cold air.

In the case of relatively small plants the self-contained producer and furnace is obviously compact. Moreover, if

it is required to substitute a furnace of this type for a coal-fired one the producer occupies practically the same space as the firegrate, and quite often an existing furnace can be replaced without interfering in any way with the

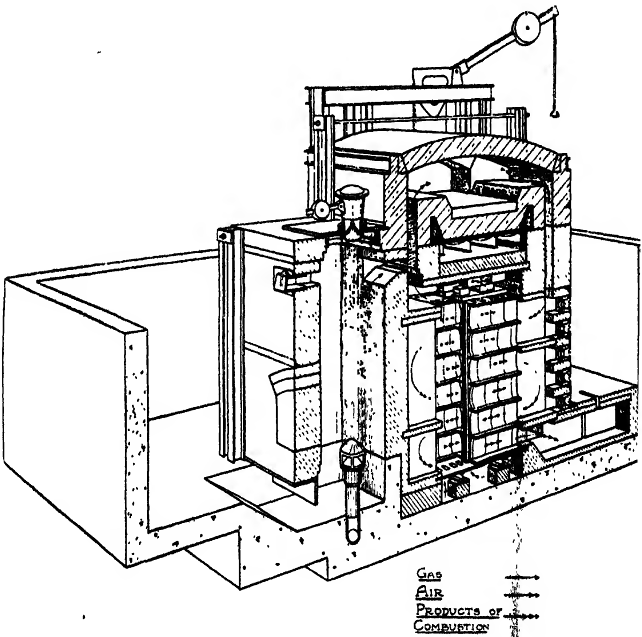


FIG. 172.—Self-Contained Furnace.

method of working. As an example of the convenience of this arrangement, the Atkinson design shown in Fig. 172 is of interest. This actual unit was designed for heating cylindrical iron lumps weighing something over 1 cwt. each, two of which form the boss of ordinary

railway coal-wagon wheels. The spokes of the wheel are placed in a die in an hydraulic press, in the centre of which are placed the two lumps. The press is then actuated, causing the metal of the lumps to flow over the spokes, thus forming a welded boss, which is then pierced

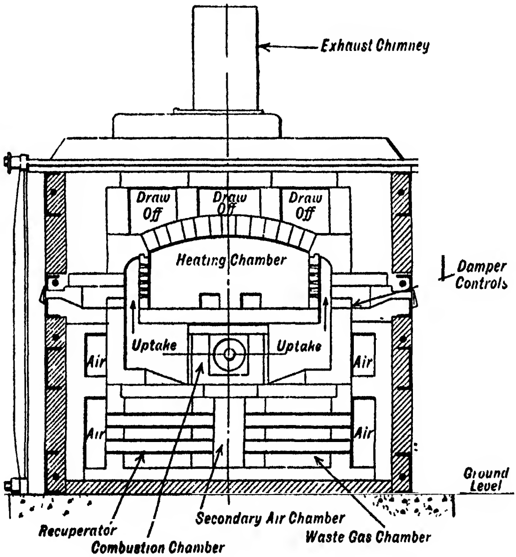


FIG. 173.—Recuperative Furnace.

in the same operation to form the hole for the axle. The furnace heats the lumps right through to high welding temperature, but a clean surface is maintained.

In Fig. 173 is shown a heat treatment furnace by the International Furnace Equipment Co. Ltd., of Birmingham. It will be seen at once that the furnace is of the

under-fired recuperative type in which the combustion air is preheated to a high degree at the expense of the energy contained in the exhaust products of combustion. It is fired by an oil burner of the medium pressure blast type, operating with a centrifugal fan, and a gas pilot jet is utilised for ignition purposes, but may be extinguished as soon as the furnace is in operation. By the use of a thermostat the air supply for the burner is kept at a constant temperature. The products of combustion first pass through the "radiant" wall of the furnace, which is so designed as to permit of the independent control of each of its zones. On this system the hot gases are only admitted to the furnace chamber through a large number of comparatively small holes, with the result that the speed of the flame is reduced, while the splitting up action produces good homogeneity of the atmosphere, the characteristics of which can be varied at will to suit various working requirements. An automatic control apparatus is fitted to hold both "atmosphere" and temperature constant at any predetermined values. From the heating chamber the hot gases pass to the recuperator below the combustion chamber. This recuperator is of the parallel flow type, with an exchange area four times as great as the total furnace floor area. Secondary air regulation is carried out at the inlet to this system. From the recuperator the gases finally find their way to the exhaust chimney, having given up as much heat as is compatible with draught requirements and having travelled along a circuit 30 ft. in length. It is claimed for this furnace that it enables tool-room accuracy to be maintained in the heat treatment department, and includes within its range every heat treatment operation demanded by modern industry.

The photo view in Fig. 174 shows a circular cell type

of furnace which is used for such operations as the black or white annealing of wire chains or small articles which

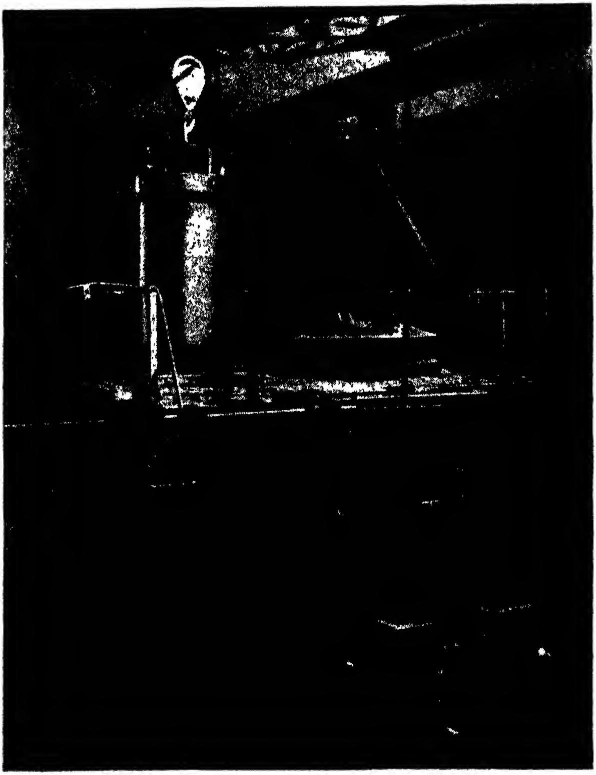


FIG. 174.—Pot-Type Furnace.

can be packed in pots. The gas-fired pot furnace works with a long rotary flame flowing spirally round and down

the circular pot within the cell. The fuel gas and the combustion air are admitted into the latter through ports tangentially disposed near its top. The air being directed against the cell wall and away from the pot while the gas flows in contact with it, the pot is always in a gaseous atmosphere, and being out of contact with the air has a long useful life; and with combustion taking place between the streams of air and gas the flame, when the pot is coming to correct temperature, is practically cylindrical. These furnaces are, of course, fitted with recuperators, which in this case are built up of a number of square section brick tubes, the gas flowing through them and the hot air rising round them. They have self-closing joints, are easy to clean, and abstract the maximum amount of heat by reason of the air flow being against the edges.

In some instances the furnace is let into the ground, so that the platform arrangement in Fig. 174 is no longer necessary. The advantage of this design of pot furnace is that it facilitates handling the work besides giving a cleaner and better appearance to the department.

Bright Annealing Furnaces

The heat treatment of metals normally carries with it the oxidisation of the surface, and this is often objectionable in that a cleaning operation such as pickling may be necessary to place the material in a fit condition for the next process.

Hence the aim, when designing annealing furnaces, is to eliminate such elements as hydrogen, oxygen, and sulphur which at high temperatures react with the metal and lead to scaling or embrittlement. This end is achieved by passing the metal through a controlled

atmosphere. One method, and probably the most usual, is mentioned on page 191.

A typical layout of a continuous bright annealing furnace designed to handle copper tube is shown at Fig. 175 and is fitted with a water spray quench, thus giving fairly quick cooling after the tubing has passed through the heating zone.

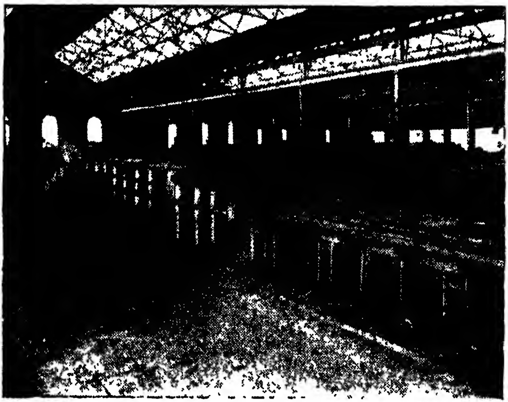


FIG. 175.—A 36-in. Gas-Fired Roller Hearth Furnace with Spray Quench for Light Annealing Copper Tube in Length.
(*By courtesy of Messrs Birlec Ltd., Birmingham.*)

Electric Furnaces for Tool Hardening

An example of the use of the electric furnace for tool hardening is shown at Fig. 176 and is by Messrs Birlec Ltd., Birmingham. The layout shows in the left-hand corner three furnaces, whilst in the centre and the right are salt baths.

FIG. 176.—Electric Furnaces for Tool Hardening using Salt Baths.
(By courtesy of Messrs Birlec Ltd., Birmingham.)

The furnaces shown are with "certain curtain" atmosphere control which has two essential features :—

(*a*) The composition of the heating chamber can be controlled over a wide range and thus adjusted to suit the requirements associated with the heat treatment of the majority of tool steels in general use.

(*b*) There is a very low loss of the hot furnace gases when the door is opened to insert or remove any workpiece; at the same time the inrush of cold air is under effective control and is very slight. This is due to the design, which directs a screen of hot gas across the aperture formed as the door is lifted.

The usual method of obtaining the desired non-scaling, non-carburising conditions in the furnace chamber is by using a closely regulated coal-gas-air mixture burnt in a special chamber.

Once the furnace has been set for temperature and atmosphere control it produces consistently scale-free work without pitting, soft spots, or a decarburised skin—and these features are obtained without the need for packing or any special preparation of the workpiece.

CHAPTER IX

LATHES

THE lathes used in the various engineering establishments are designed with one aim in view, namely, to remove surplus metal and produce parts to the specified dimensional accuracy, also surface finish. Yet the range of manufactured articles cover such a wide field that over the years modifications have been made to the old designs and new ones introduced to meet known production requirements. Hence within the space limitations of this work it is impossible to illustrate the many types of production equipment coming under the general heading of a lathe.

From the above it follows that any attempt at classifying all the lathes now in use would, because of overlapping, be very difficult, and it is doubtful if such efforts would serve any useful purpose. The modern tendency is towards designing the lathe around the job to be done. Hence for general purposes, as in a toolroom or engineering shop handling a wide range of small orders, the standard centre lathe is usually the first choice; where screwed plug gauges have to be screw-cut, a lathe may be obtained designed specifically for this purpose; similarly, one will find lathes specially designed for turning automobile crankshafts, turning and boring wheels for railway plant, and large fly-wheels and pulleys.

The majority of lathes now offered by the various firms

can be relied upon to give a good production per hour on work held within reasonable limits. As in other spheres, a well designed and made machine will inevitably cost more than an inferior article; one does not get a Rolls Royce motor car for the price of a Ford 8 or 10 horse-power car. But usually it will be found that the higher priced machine justifies its extra initial costs by its higher hourly output and lower maintenance charge. Yet there may be conditions operating where the cheaper machine gives results as satisfactory as those obtained from the more expensive type. Therefore in all instances the potential buyer should give careful attention to the economics of the position, and so far as circumstances permit, draw up an estimate showing the all-in cost of running each make of machine when engaged on the known range of work. Full use should also be made of the alignment tests as prepared by the Institution of Mechanical Engineers.

The selection of a lathe, and the question as to which is the best type of machine for any particular shop, depend entirely upon the class and size of work which is now being and in the future likely to be carried out in that particular concern. When orders for one or more components run into very large numbers, then the selection of the lathes for each operation is of utmost importance. In fact it is often desirable to have the machines specially designed for the purpose, or have suitable modifications made to the existing equipment.

It is obviously uneconomical to use a heavy type of sliding surfacing and screw-cutting lathe for machining light, plain work. It is also unprofitable to have a number of machines standing idle for want of a specialised class of work. For these reasons a considerable amount of thought should be given to the general question of com-

bined and individual output of all lathes. The loss occasioned by several small machines standing idle might be no greater than that caused by the breakdown or idleness of one large lathe. Therefore it is most important that each machine shop should be equipped with lathes of a size suitable for performing the full range of work, now and in the near future, likely to be handled. At the same time the aim must be to obtain the maximum output with the minimum number of stoppages from breakdowns arising from any cause whatsoever.

The modern tool-room and general manufacturing lathes are often very complex machines, and this is chiefly due to the great variety of accessories with which they may be fitted in order to deal with special operations. Such processes as the relieving of milling cutter teeth, form or ball turning, taper screwing, and lathe milling require accessories, whilst additions to the lathe, such as carriage reversing devices, automatic stops, and micrometer adjustments, although in most cases making for ease of working, all tend to complicate the design of the machine.

In the United Kingdom the size of a lathe is generally indicated by a distance taken from the lathe centre to the top of the bed, and by the maximum length that can be taken between the lathe centres. Two other important dimensions are often given, one being the amount of swing over the lathe saddle, and the other, in case of a gap bed lathe, the greatest diameter of swing when the gap is removed.

In all cases each lathe should be proportioned according to the horse-power input and be rigid enough to withstand the heaviest permissible cut without excessive strain. The bed should have ample bearing surface to properly support the saddle.

The fast headstock should have bearing surfaces of ample proportions or anti-friction bearings of adequate size, whilst a large diameter hollow spindle should be

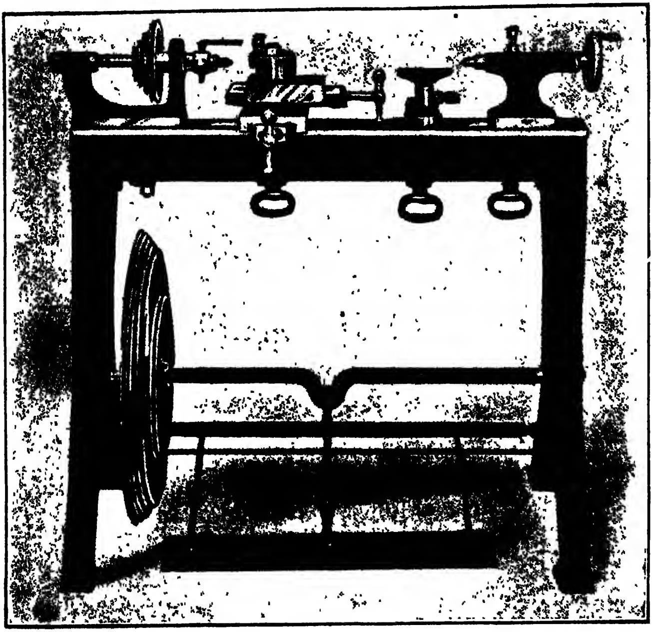


FIG. 177.—Small Foot Lathe.

fitted. Into the main design a simple and effective method of lubrication should be incorporated. Over the past years there has been a steady drift towards the design of an all-geared headstock, as shown at Fig. 182, and away from the cone pulley machine, illustrated at Fig. 178.

The tailstock or poppet should be proportionally rigid

to the fast headstock, with the spindle large, ground accurately to size, and be fitted with a reliable locking attachment. The screw is best if left handed, and suitable means of adjustment should be provided at the back of the hand wheel to take up wear between the collar and its bearings. Some form of arrangement should be fitted by means of which it is possible to adjust the tailstock with the machine spindle.

The saddle or carriage should be provided with large bearing surfaces, and should move in the same direction as the handle (see the relevant B.S.S.).

The lead screw, being one of the most important parts of the lathe, should be accurately cut within the accepted limits, and some simple and effective arrangement should be fitted in order that the screw-cutting mechanism may be connected and disconnected as required.

With lathes of modern design the automatic sliding and surfacing motion is obtained from a feed shaft and not direct from the lead screw (compare Figs. 179 and 182).

Foot Lathes

The simplest type of lathe for metal turning, of an amateur type, is illustrated in Fig. 177. In this example the beds are made V, and flat. The fast headstock is of simple design with a hardened steel spindle revolving in a conical bush, and is provided with an adjustable back centre. Wherever possible, the wearing parts are hardened, ground, and lapped until a fine finish and good fit are obtained.

The compound slide rest has square thread screws, phosphor bronze nuts, and balanced steel handles. The

top slide can be swivelled to degrees marked on its base.

A crankshaft of steel, hardened at the wearing parts and run on adjustable bearings, is driven by means of a suitable wrought-iron treadle.

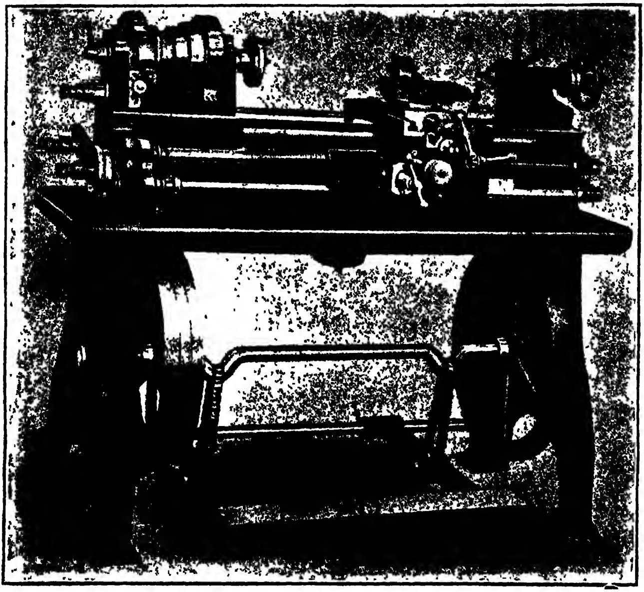


FIG. 178.—Foot Lathe with Sliding Surfacing and Screw-Cutting Movements.

A heavier and more useful type of foot lathe for use where electrical or other power is not available is shown in Fig. 178. The machine is fitted with a lead screw and has a separate shaft for automatic sliding and surfacing movements.

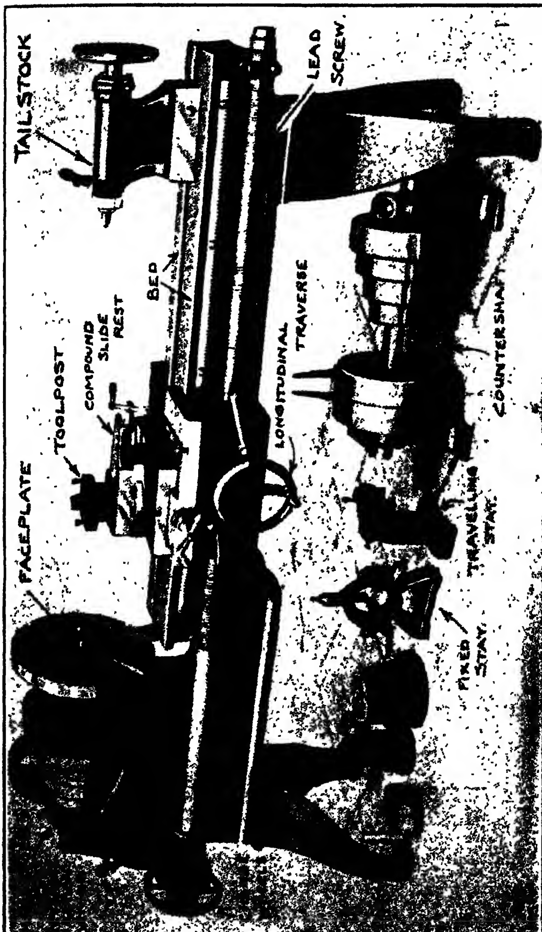


Fig. 179.—A Cone Pulley-Driven Screw-Cutting Lathe (old type machine). (Compare the design with Figs. 182 and 183.)

The headstock is provided with a back gear and is fitted with a hollow steel spindle, running in parallel gun-metal bearings, having a hole through its entire length. The drive is through the medium of a foot treadle and double crankshaft, the latter being fitted with a fly-wheel and three-speed cone pulley.

The tailstock can be set over, and is provided with a locking arrangement. The saddle moves on a flat bed; it has planed T slots, and is fitted with a compound slide rest which is marked in degrees.

A tumbler gear connected directly to a wheel on the lathe spindle allows the lead screw to be reversed.

Power Lathes

A small old-type power-driven cone pulley screw-cutting lathe is illustrated in Fig. 179. The countershaft and some of the lathe accessories are also shown.

Lathe Surfacing Feed

For the purpose of automatically surfacing work, motion is in this design transmitted from the lead screw by means of worm, spur, and bevel gears. The ratio between the speed of the lead screw and the speed of the slide rest screw can be found by obtaining the product of the teeth in the driving gears and the teeth-driven gears.

Sliding Feed

When, as in Fig. 179, a lathe is not fitted with a separate shaft for giving an automatic sliding feed, the lead screw

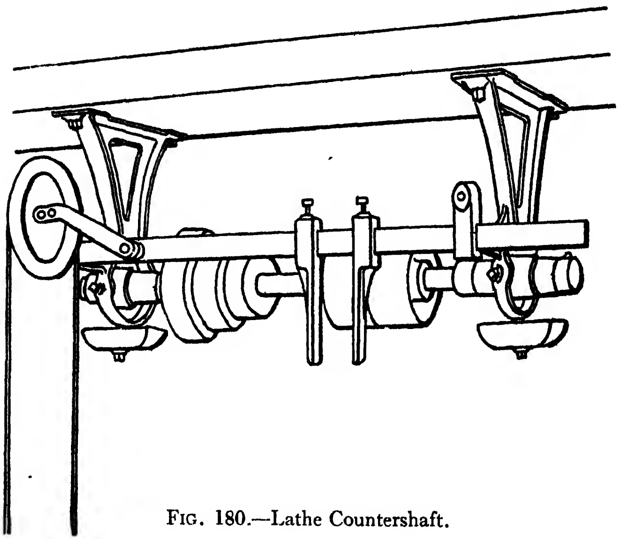


FIG. 180.—Lathe Countershaft.

is used instead by simply putting on a compound train of wheels that will give a very fine thread. Whilst this simplifies the design and reduces the cost of manufacture, it is not regarded as good practice.

The Back Gear

The following is a description of the usual type of back gear as fitted to a cone pulley machine :—

On the lathe spindle is keyed what is known as the

driving plate or gear, the step-cone pulley and attached pinion being free to revolve if desired. The back shaft has a wheel and pinion keyed on to it, and can be drawn into gear either by an eccentric motion or by sliding.

When using the back gear reduction, the cone pulley is freed from the driving gear and the back shaft gears are put into mesh.

When running without the back gear, the back gearing is taken out of mesh and the cone pulley is connected to the driving gear by means of a bolt or pin.

Thus when running with the back gear in mesh the motion is transmitted from the countershaft to the cone pulley, which runs free on the lathe spindle and drives the back shaft through the medium of the cone pulley pinion, meshing the large back-shaft gears. This in turn drives the lathe spindle via the back-shaft pinion and spindle driving gear.

The object of the back gear is to increase the range of speeds and to enable one to make full use of the horse-power input. Hence it is often necessary to know what reduction of speed can actually be obtained.

Taking an example. On an 8-in. lathe the cone pulley has four steps, the diameter of each being respectively $3\frac{5}{8}$ in., $5\frac{1}{8}$ in., $6\frac{5}{8}$ in., and $8\frac{1}{8}$ in. The countershaft pulley revolves at 100 revolutions per minute. The pinions on the lathe spindle and back shaft have each 16 teeth, and the wheels themselves have 48 teeth. To find the various speeds—

$$\frac{16 \times 16}{48 \times 48} = \frac{1}{9},$$

or the back gear will reduce the velocity of the lathe spindle compared with the cone pulley as 1 is to 9. Hence

for each step the cone pulley revolves in revolutions per minute nine times as fast as the lathe spindle.

The cone pulley having four speeds, by using the back gear eight different speeds can be obtained, these being—

$$\text{Speed without back gear } \frac{100\times 8\frac{1}{8}}{3\frac{5}{8}}=224{\cdot}1.$$

$$\text{,, ,, ,, } \frac{100\times 6\frac{5}{8}}{5\frac{1}{8}}=129{\cdot}2.$$

$$\text{,, ,, ,, } \frac{100\times 5\frac{1}{8}}{6\frac{5}{8}}=77{\cdot}3.$$

$$\text{,, ,, ,, } \frac{100\times 3\frac{5}{8}}{8\frac{1}{8}}=44{\cdot}6.$$

$$\text{Speed with back gear } \frac{224{\cdot}1}{9}=24{\cdot}9.$$

$$\text{,, ,, ,, } \frac{129{\cdot}2}{9}=14{\cdot}3.$$

$$\text{,, ,, ,, } \frac{77{\cdot}3}{9}=8{\cdot}6.$$

$$\text{,, ,, ,, } \frac{44{\cdot}6}{9}=\text{say } 5.$$

The eight speeds obtained being 5, 8.6, 14.3, 24.9, 44.6, 77.3, 129.2, and 224 r.p.m.

Small Bench Lathe

Fig. 181 illustrates a small type bench lathe with a cone pulley drive as is used for the production of small instrument parts, small tools and gauges, punches and beds for press tools. This type of machine is in all respects identical with the larger centre lathes as are used in the toolroom and for general engineering purposes.

For the machine shown on p. 216, the drive is off a line shaft or from a ½ horse-power motor via a two-speed

ball-bearing countershaft. The machine spindle is hardened, ground, and lapped to suit the conical bearings.

The method of holding the workpiece varies; one may use the chuck either a three-jaw self-centring or a four-jaw independent, the drawback collet arrangement, or place the workpiece between the centres.

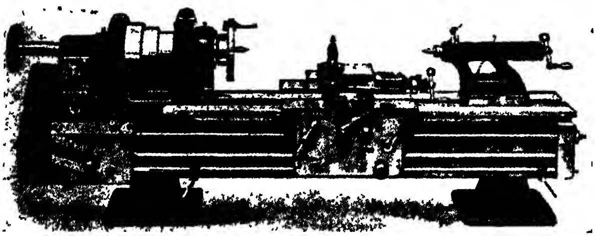


FIG. 181.—A 4-in. Centre Holbrook Bench Lathe with Sliding, Surfacing and Screw-Cutting Motions.

On the saddle is mounted a compound slide which may be swivelled to cut the desired taper. The saddle itself has double bearings to all shafts, and friction clutches are used to engage the feed mechanism for both surfacing and traversing. A thread-indicating dial eases the work of "picking-up" an odd pitch. As on all good designs the screw-cutting and feed mechanisms are interlocked, so that as one is engaged the other is taken out of mesh, and in this way the danger of stripping the gear teeth is avoided.

A quick-change gear box permits a wide range of threads to be cut, and by the introduction of a translation wheel metric pitches can also be produced.

An 8-in. Centre Lathe

At Fig. 182 is shown a Lang centre lathe for surfacing, sliding, and screw-cutting which has a 16-in. swing or 8-in. centres. The headstock has twelve forward and four reverse speeds. The quick-change gear box gives a range of twenty-eight feeds with the lever at "normal" and the

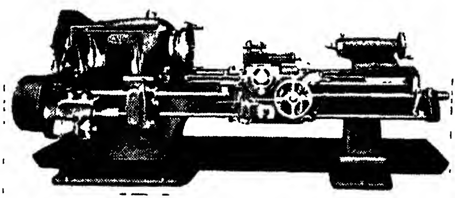


FIG. 182.—An 8-in. Centre Lathe by Langs of Johnstone for Sliding, Surfacing, and Screw-Cutting.

(By courtesy of Messrs Lang Ltd., Johnstone.)

same when the lever is moved to the "coarse" position. For screw-cutting, 2 to 28 threads per inch may be obtained via the gear box, with the lever set at "normal" and 0.5 to 7 threads per inch when it is placed at "coarse." Arrangements are provided in the design so that pick-off gears can be used to give an odd pitch when this is required.

The tool slide shown in the illustration is of the four-bolt type, but either a square or a single bolt type can be fitted when required.

Tangyes 8½-in. Centre S.S. and S.C. Lathe

The general purpose lathe at Fig. 183 has been designed for heavy cutting on a wide range of work and is of the gap type with a removable piece fitted in the bed to enable large diameters to be turned. When necessary a taper turning attachment is also provided. On a 9-ft.

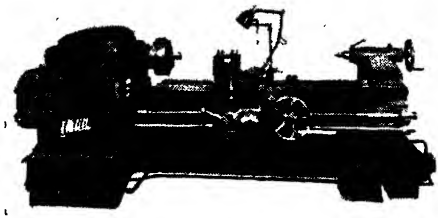


FIG. 183.—An All-Geared Centre Lathe, 8½-in. Centre.
(*By courtesy of Messrs Tangyes Ltd., Birmingham.*)

6-in. bed, a component having a length of 4 ft. 6 in. can be admitted between the centres. Work up to 17 in. diameter can be swung over the bed and up to 12 in. diameter over the saddle. With the gap piece removed, 30½ in. diameter can be swung with a 10½ in. from the front of the face plate.

The bed is of very strong construction with square machine ways, with a narrow guide for receiving the saddle. The width over the top surfaces of the bed is 16 in., the depth on the body being 12 in.

The fast headstock is of a modern design and carries a large-diameter hollow spindle made from a high-carbon steel forging, accurately ground, and running parallel,

to capped phosphor-bronze bearings with a ball race to take the end thrust. The front bearing is 5 in. diameter, $5\frac{1}{2}$ in. long, and the rear $3\frac{3}{8}$ in. diameter, 4 in. long. The spindle is bored $2\frac{3}{8}$ in. diameter right through, the front end being arranged to carry a No. 4 Morse taper centre. Vertically below the main spindle is the secondary driving shaft ; all the other gears are carried on shafts in the bed, thus keeping the weight as low as possible. Three speed ranges are selected by a hand lever on the front of the headstock. On the fast range, 200 to 600 revolutions per minute, the main spindle is driven direct by a triplex roller chain from the input clutch shaft in the base. For the intermediate and slow ranges, 50 to 150 revolutions per minute and 9 to 38 revolutions per minute, the drive is through reduction gearing.

The main drive is from a 6 B.H.P. variable speed A.C. commutator motor, giving 500 to 1,500 revolutions per minute, a constant torque, mounted on a base plate at the back of the machine, through V ropes to the input shaft, thence through a multi-disc plate clutch to the roller chain drive or the reduction gears to the main spindle.

The clutch, in which is incorporated a brake, is operated by a conveniently placed hand lever near the face plate to start the main spindle or quickly bring it to rest.

The speed of the main motor is varied by means of a pilot motor control by a push-button unit on the front of the headstock having four buttons, "Start," "Raise Speed," "Lower Speed," and "Stop." A tachometer is fitted which enables the operator to read the spindle speed. When the stop button is pressed, the motor always returns automatically to give the slowest speed in the range to which the gear lever is set before it can be started again.

The automatic force feed lubrication system of the headstock is self-contained and is provided by a plunger pump driven from the input shaft. When the spindle is stopped by disengaging the clutch the pump stops, but the clutch plates are continually lubricated by splash. A strainer on the suction end of the piping is easily accessible for cleaning from the rear of the machine. A glass dome flow indicator on the front of the headstock shows that the pump is working.

The feed drive is taken from the headstock through the feed reverse mechanism, which is used for cutting left-hand or right-hand threads, through change wheels mounted on a quadrant at the end of the bed. These are enclosed in a box with a hinged door, the lubrication being connected to the main system. A quick-change feed gear box enables twenty-eight different feeds or threads to be cut without altering the change wheels, which means that with change wheels of 40 driver and 80 driver all the common Whitworth, B.S.F., and gas threads can be selected by levers only. With equal change wheels the twenty-eight sliding feeds would be from 12 to 168 cuts per inch and the surfacing feeds 24 to 336 cuts per inch.

A lever at the front interlocks the lead screw and feed shaft, preventing them being in operation together. The feed shaft is $1\frac{1}{4}$ in. diameter and is driven through an enclosed slipping safety clutch, which prevents damage to the mechanism through overload.

The accurately cut coarse pitch lead screw is $1\frac{3}{4}$-in. diameter 0.5-in. pitch Acme thread, and is carried between brackets attached to the bed. The lead screw is adjusted in tension with a ball-thrust bearing at each end. The lead screw can easily be removed without disturbing its drive from the feed box.

The loose headstock or tailstock carries a $2\frac{1}{2}$-in. diameter spindle, adjustable by means of a screw, nuts, and hand wheels. The spindle is locked in position by means of a bolt and pads. The head can be set over for taper turning by a screw.

The saddle and slider are arranged for sliding, surfacing, and screw-cutting, all having self-acting motions and being reversible. The compound tool rest has a substantial graduated swivel base for turning tapers by hand, all the slides having adjustable taper gibs for wear. A square turret can be supplied to replace the compound tool rest if required. Large diameter micrometer dials are fitted to the traverse screws on the slides. The largest diameter that can be faced at one setting is $30\frac{1}{2}$ in. Knife-edge wipers are fitted to the saddle to prevent sway damage to the bed ways. A handle is fitted for locking the saddle to the bed while surfacing, and a clear threading dial is provided for use when screw cutting.

The self-acting feed in the apron is taken from the feed shaft through a drop worm running in an oil bath. This is actuated by a single lever and is interlocked with the lever engaging the clam nuts on the lead screw. A "one shot" lubrication system is provided for the saddle and apron and grease nipples for the other points.

An extension at the back of the saddle carries the taper-turning attachment which, when required, will turn tapers up to $10°$ each way and 20 in. long at one setting.

An electric centrifugal suds pump fitted to the sump at the end of the bed, well away from all cuttings, supplies coolant to the turning tool through a flexible pipe and adjustable arm. The suds tray allows swarf to be easily removed.

On the headstock are mounted three coloured lamps

which indicate to the operator when the main motor is running when the isolating switch is in, and when the suds pump is working. This is an advantage in a noisy shop, where motors can be left running unnecessarily.

An adjustable arm carrying a 50-volt electric lamp is fitted on the back of the saddle and travels with the turning tool. A transformer switch fuse unit reduces the voltage.

The machine is completely self-contained, all the electrical control gear being mounted on a slate base and housed in a case below the front of the headstock. The cover is interlocked with the handle of the isolating switch and, when removed, allows easy access to the wiring.

A 14-in. Centre Lathe

A larger size of centre lathe is shown at Fig. 184, and

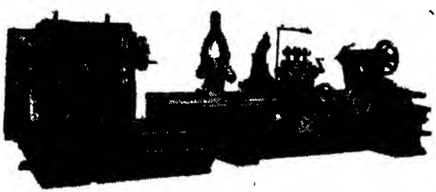


FIG. 184.—A 14-in. Centre Lathe. Note the three point and the travelling steadies.
(*By courtesy of Messrs Tangyes Ltd., Birmingham.*)

this, too, follows the general tendency in design by having an all-geared head and an independent motor drive. On this machine an attachment has been included

for the turning of locomotive axles, an auxiliary slide being fitted to the saddle for this purpose. A former plate held by brackets can be clamped into the desired position at the rear of the bed. When the lathe is not required for turning the "waist" on a locomotive axle, the forming attachment can be disconnected and the auxiliary slide locked in position; then the usual turning, boring, facing, and screwing operation can be performed.

The Bed of a Lathe

The bed of a lathe should be of sufficient depth and width to give the greatest rigidity under heavy cuts and at the same time be strongly braced internally by cross members carefully placed to avoid distortion of the main casting.

The bearing surfaces may follow the normal English practice and be of the flat type (see Figs. 183 and 184) or of the American design, having a V shape similar to the cross section featuring at Fig. 185, where the vees, with a 90° included angle, have the tops rounded to prevent bruising. Irrespective of cross section, the bearing surfaces are either accurately scraped or ground so as to ensure perfect alignment and a long life. The feed rack is made from steel and, with the exception of the very long lathes, is in one piece.

A light, unsupported saddle will answer for light cuts on large diameters with the cutting tool directly above the front shear or bearing surface of the bed, but the stresses are of a different character when the lathe is taking a heavy cut on a small diameter. In Fig. 186 the position of the tool and compound slide rest is shown when the

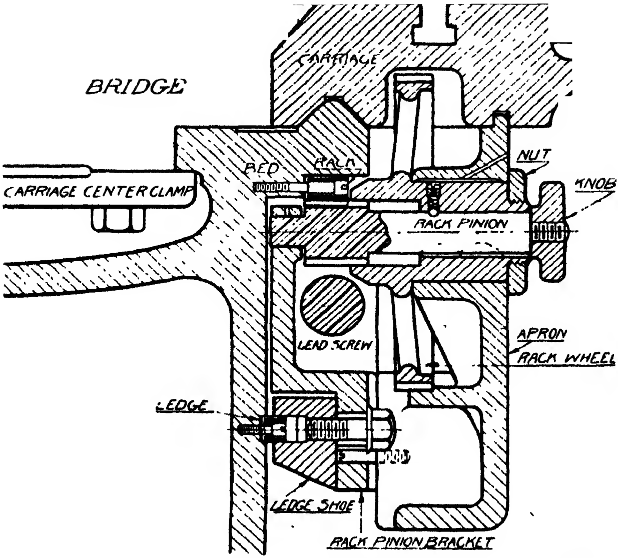


FIG. 185.—Part Section through Bed and Apron of a Lathe without Feed Shaft.

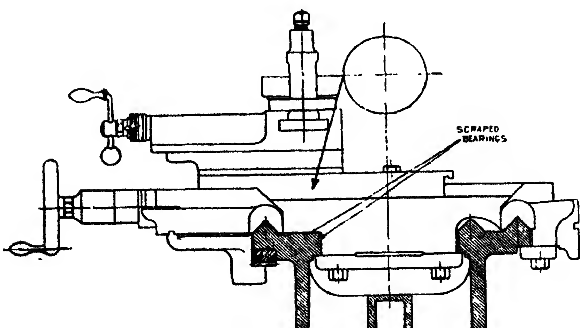


FIG. 186.—Stresses on Lathe Bed.

lathe is working on a relatively small diameter. The arrow indicates the direction of pressure due to the cut, and to take the resultant thrust the top and inside surfaces of the bed are scraped or ground, thus forming a supplementary bearing at right angles to the bed. In this way support is given to the saddle just where it is needed, hence preventing deflection under heavy cuts.

Carriage and Apron Unit

The carriage or saddle and apron unit of a Holbrook lathe is shown at Fig. 187. Bed covers incorporating felt wipers are fitted at each end of the carriage or saddle to wipe clean the surface of the lathe bed, thus preventing grit and swarf from destroying the accuracy of the machine. A high-pressure oiling system ensures adequate lubrication of the carriage ways.

The apron supports the shafts at both ends and has fitted a split phosphor-bronze nut for the lead screw.

The feeds have finger-tip control (see Fig. 188) for both surfacing and traversing, and may be either manually or power driven. When under power the feed is stopped by using a push-and-pull knob in the hand-wheel spindle so that no undue strain is imposed upon the gearing, which would destroy the accuracy of any thread cut on the machine. As one would expect, the necessary safety device is incorporated into the design so that the feeding and screw-cutting mechanisms are separately operated. Full use is made of roller and thrust bearings wherever necessary.

The main spindle may be stopped, started, or reversed by the lower lever on the right of the apron. Before

moving the lever into the reverse position it is necessary to depress the safety trigger, as the latter is provided so that the spindle is not accidentally reversed.

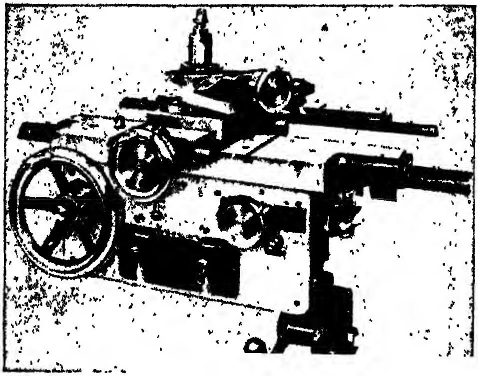


FIG. 187. Carriage and Apron Unit of a Holbrook Lathe.

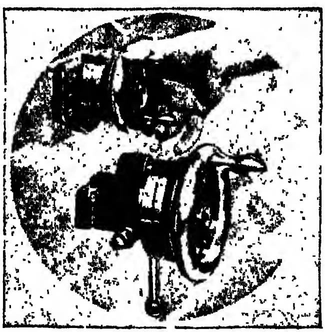


FIG. 188. Showing Finger-Tip Control of a Holbrook Lathe.

Also fitted are threading and distance travelling dials, the two being within easy vision of the operator, whilst a quick withdrawal mechanism for both internal and external work re-positions itself with accuracy.

The top slide may be swung to any position around 360°, and the hand wheel is clear of the cross-slide hand wheel. A pillar type of tool-holder is fitted and has an elevating piece for adjusting the cutting edge to the correct height. The large micrometer dials give a reading to 0.001 in., and easy locking without disturbing the setting is by means of a knurled screw on the front of the hand wheel.

Fig. 188A illustrates the internal mechanism of a Holbrook

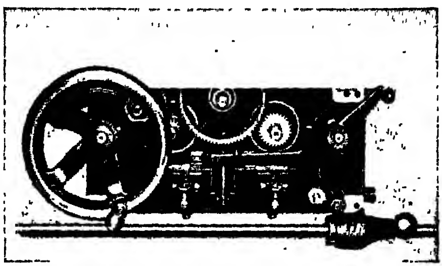


FIG. 188A.—View of a Lathe Apron with Front Plate Removed showing Feed Mechanism.

lathe with the front plate removed to show the feed gearing. The two steel worms, just visible in their housings, are driven by means of spur gears off the feed shaft. When required, the worms are lifted into mesh with the phosphor-bronze worm wheels by means of the levers. The worm to the left controls the sliding of the

carriage, whilst that to the right operates the cross slide. The safety lever which prevents the screw-cutting and feed mechanisms from being engaged simultaneously may be seen. The lead screw, not clearly shown, lies to the rear of the apron casting and is guided by means of a hardened steel bush. The split nut which mates the lead screw when cutting a thread also lies at the back of the apron casting, hence cannot be seen. All gears in the apron, excepting the worm wheels, are of steel, and each shaft has a double bearing.

The Tailstock

The lathe tailstock, one design of which is shown at Fig. 189, is used for such purposes as supporting the

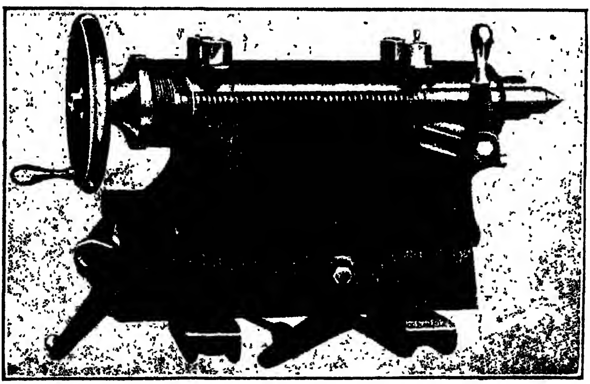


FIG. 189.—Lathe Tailstock.

work when running between the centres or when a long component has to be held in a chuck. It is also used for holding such tools as a drill, reamer, or tap. On the small machines the tailstock is readily moved by hand into any desired position on the lathe bed; given the larger machines where there is a considerable weight to slide along, a rack and pinion device is used. The means of clamping the tailstock or poppet in position on the lathe bed varies, hence one finds the designer choosing (*a*) one or more bolts and nuts and clamping plates, (*b*) a lever operating an eccentric which in turn controls the clamping plate or plates. The front end of the tailstock barrel is normally bored to a Morse taper for the fixed or revolving centre and the various cutting tools mentioned above. Axial adjustment is by means of the hand wheel, which is keyed to the square thread screw.

Compound Rest

The compound rest, one design of which is illustrated in Fig. 190, is provided with four locking bolts, two on each side of the swivel base. Both the upper and lower slides are fitted with taper gibs, which are tongued into the grooves of the slides, so that no amount of strain will displace them. The round end screws, one on each end, take up the wear the entire length of the gib, and allow sensitive adjustment.

The top slide is provided with a tee slot to hold the tool post and is so placed that the tool has a support close to its cutting edge and need not be extended far from the tool post. The rest is graduated for any angle up to 90°. The cross feed and top slide screws are provided with micrometer adjustment reading to thousandths of an inch.

The above method of clamping the tool in position is also shown below at Fig. 190, but for the larger machines preference is often given to the use of two straps and four bolts, as are shown at Figs. 183-184

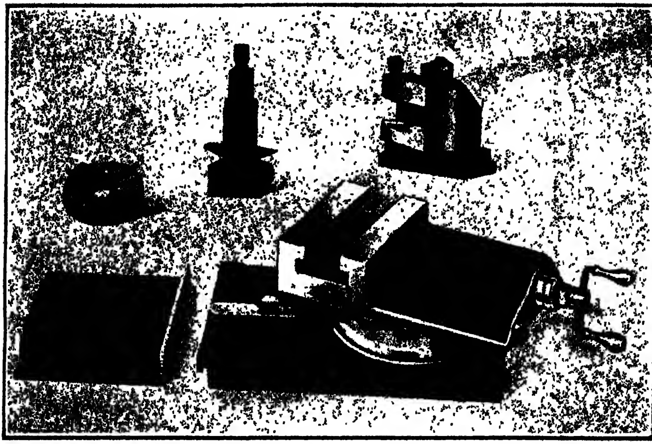


FIG. 190.—Details of Compound Slide Rest.

Occasions may arise where the square turret tool post as fitted to capstan and turret lathes may prove to be the most suitable for the class of work being handled within the establishment.

Quick-Change Gear Box

The quick-change gear box as shown at Fig. 191, with the tumbler gearing shown at the bottom, is one fitted to a Holbrook lathe. The value of a unit of this type is that it no longer becomes necessary to have to work out

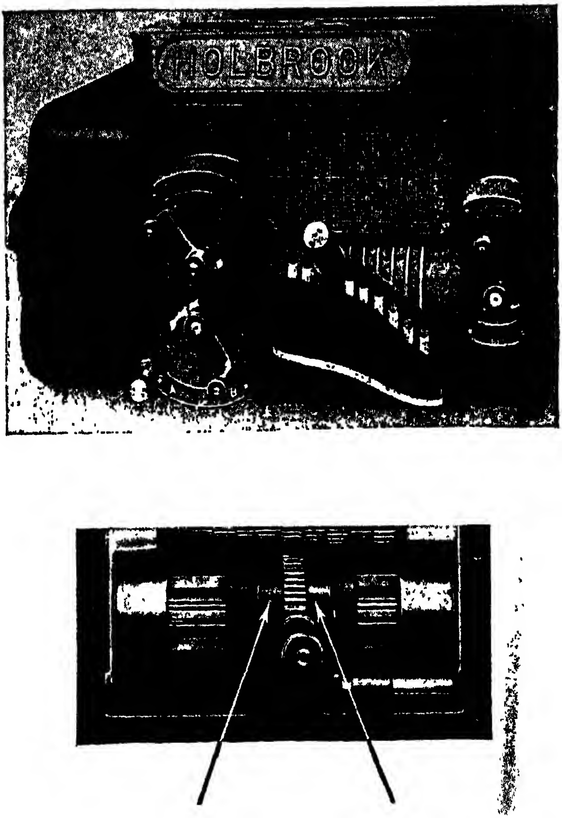


FIG. 191. Holbrook Quick-Change Lathe Gear Box and Tumbler.

and then set up a gear train each time a thread has to be cut or a specific feed is required. All that is necessary is to move one or more levers into the desired position. The index plate, as shown in the illustration, clearly indicates the location of the lever for each thread, and with the gear box as shown, direct changing enables sixty pitches ranging from 1.25 to 0.013 in. to be cut; by the introduction of a translation wheel, thirty-six metric pitches can also be cut ranging from 0.35 to 7 mm.

CHAPTER X

TOOL-HOLDERS

THE advantages of tool-holders over the solid type of cutting tool when made throughout in one material are :—

1. The facility with which the cutting edge of the tool can be adjusted to its correct height.

2. The ease with which the cutting tool itself can be removed and replaced.

3. The small amount of expensive tool metal required.

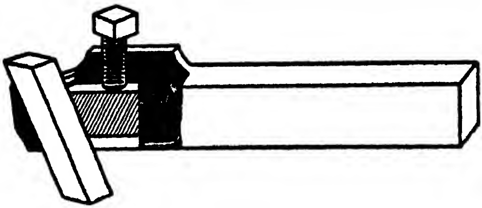


FIG. 192—Tool-Holder for Square Section Steel.

The cost of modern high-speed steel, and of alloys such as are used in the manufacture of Stellite, often prohibits the use of solid tools of heavy section.

Many of the best cutting steels are somewhat brittle, and if clamped on a dirty surface the resultant bending moment will crack the hard material.

A good type of tool-holder is undoubtedly a means of saving money and time, and its use is strongly to be recommended in conjunction with the best quality of high-speed cutting metal. Alternatively a butt welded tool may be chosen, see Fig. 208, page 243.

A simple form of tool-holder is illustrated in Fig. 192. This type of holder will be found very useful for holding square section tools "on end." It has been found par-

ticularly useful for gripping Stellite, as, when used in this position, the very hard scale of the alloy is presented to the surface of the work where the rubbing takes place. It allows the tool to be easily ground to the desired top and side rake, and also adjusted for height. When adjusting the tool for height, the small set-screw at the top is slacked back, and the tool is pushed into position; on tightening up the set-screw, the tool is firmly held by means of a wedge-piece, which effectually prevents the tool from moving.

It may be mentioned here that Stellite is an extremely

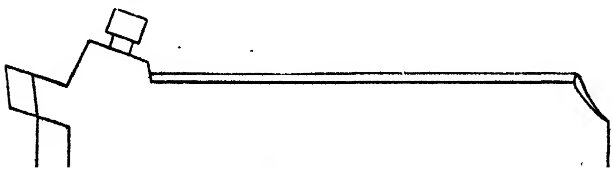


Fig. 193.—The "Weston" Tool-Holder.

hard metal composed chiefly of cobalt and chromium. It cannot be hardened, and heat has no effect on its cutting qualities until a temperature of 1,000° F. is reached. It is cast into a variety of shapes, and can be reduced in size only by grinding. For most purposes the square section is suitable, and either of the tool-holders shown in Figs. 192 and 193 can be used. The holder shown in Fig. 193, known as the Weston holder, not only affords the maximum support to the cutter through the projecting lip and the cutter nose, but also provides the necessary amount of top rake. This feature is particularly desirable, as it tends to maintain unimpaired the exceptional cutting properties of Stellite just where it is most wanted, namely, at the top surface of the cutter.

A right-hand side tool-holder for square section tools is

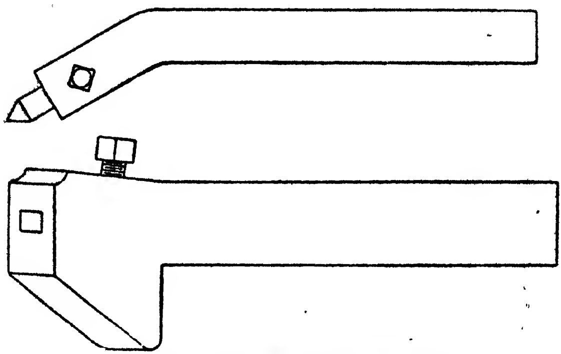


Fig. 194.—Right Hand Side Tool-Holder

shown in Fig. 194. The front part of this type of holder is set either to the right or left as desired, and the tool is held in position by the direct pressure of the set-screw. This type of holder is very suitable for heavy work.

Swivel Holders

A three-way swivel tool-holder is shown in Fig. 195. This is usually fitted with square section tools, and takes

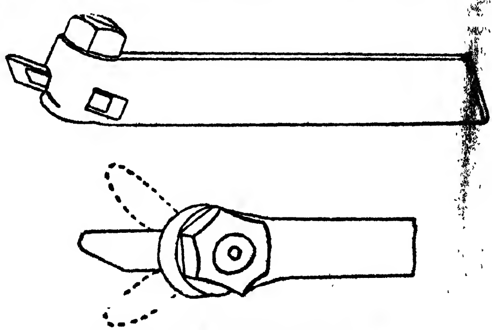


Fig. 195.—Three-Way Tool-Holder.

the place of three ordinary tool-holders. It can be adjusted for right-hand, left-hand, or straight turning. The cutter is locked in any of the positions, and the tool post, which sets at an angle with the body, gives the proper rake. When in the off-set position, owing to the angle of the tool

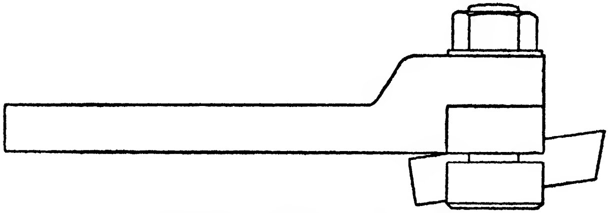


FIG. 196.—Swivel Tool-Holder.

post, the cutting edge is raised, giving an additional side rake which obviates the necessity of grinding a lip on the cutter. This holder is made of drop forged steel, afterwards case-hardened, and is known as the "Carr" three-way tool-holder.

Another type of three-way tool-holder is shown in Fig.

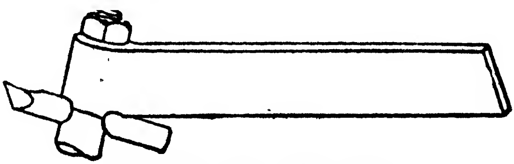


FIG. 197.—Swivel Tool-Holder.

196. This holder takes a V section tool only, and is intended for use in planing and shaping machines as well as in lathes. The cutter itself can be shaped for screw-cutting, parting off, or any other form of tool.

A simple type of swivel tool-holder suitable for comparatively light work is illustrated in Fig. 197. In this

case the section of the tool is round, and suitable semi-circular slots are provided to allow the tool to be held in the various positions.

Screw-Cutting Tool-Holders

The tool-holder shown in Fig. 198 is intended to hold a special form of thread cutter. The tool is ground on

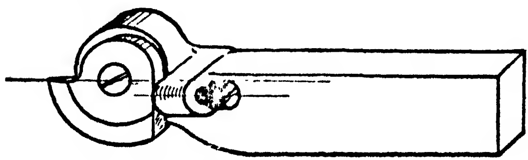


FIG. 198.—Screw Thread Tool-Holder.

the cutting edge to the correct angle. It can be rotated on the pin provided, and can be adjusted for height, when

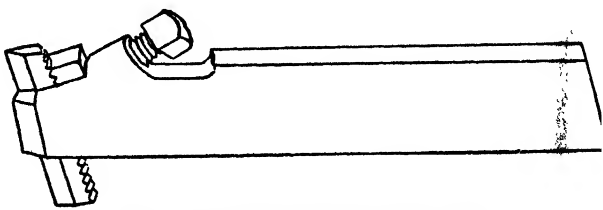


FIG. 199.—Holder for Screw-Cutting Tool.

necessary, by means of a screw. This holder allows of the use of a simple and effective cutter for V threads.

A different type of screw-thread tool-holder is shown in Fig. 199. The cutter is of special shape, the back part

being serrated in order that a loose piece, similarly serrated, may be able to hold it firmly in position.

An improved type of holder is illustrated in Fig. 200. The tool in this case is suitably serrated at the side, and is

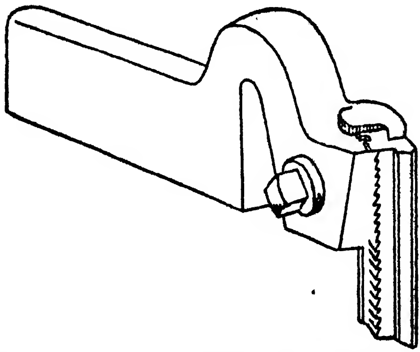


FIG. 200.—Spring Tool-Holder for Screw-Cutting Tools.

held in position by means of a loose clamp. The holder is made similar in shape to a spring tool, and therefore

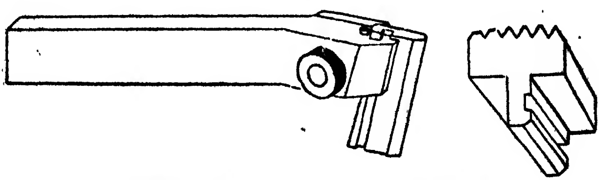


FIG. 201.—Tool-Holder for Thread Chasers.

it is possible to take fine cuts and give a good finish to the thread being cut. It is usual with this type of tool to use a different cutter for each different pitch. The cutters are specially made, so that when the cut is taken to the correct depth the top of the thread is rounded off to the required amount.

Fig. 201 shows still another type of screw-thread tool-holder, which will be found to give satisfaction as the tool is firmly held. For finishing threads, a form of chaser is used similar to that shown in the illustration, but conforming to the pitch and standard required.

Parting-Off Tool-Holders

With the ordinary type of parting tool made from solid bars, the percentage of breakages is very high, and there-

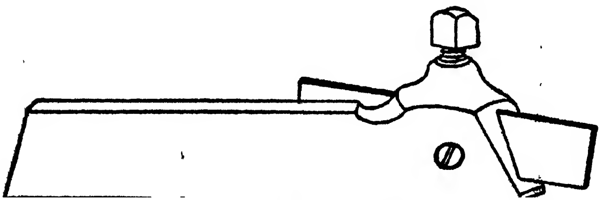


FIG. 202.—Parting-Off Tool-Holder.

fore with this particular tool the tool-holder principle is most economical and at the same time very effective. Fig. 202 illustrates an off-set parting tool-holder. The blades are usually made from high-speed steel, and are bevelled on both sides, thus giving the proper clearance to ensure a clean-cutting tool.

Boring Tool-Holders

A very simple form of boring bar tool-holder for small work is illustrated in Fig. 203. Here the holder simply

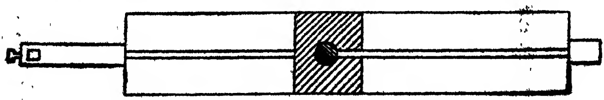


FIG. 203.—Tool-Holder for Boring Tool.

consists of a piece of oblong or square section steel, bored out, and slotted at one side. A boring bar of suitable size

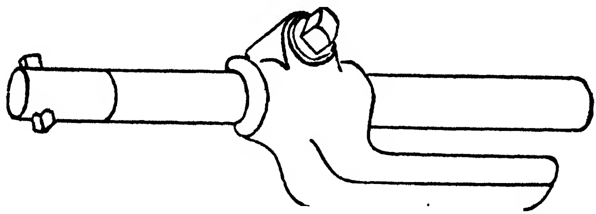


FIG. 204.—Tool-Holder for Boring Bar.

is used, and this is held in position by the holding-down dogs of the tool-holder.

Fig. 204 shows another simple and effective type of holder. This consists of a forging bored out to take the

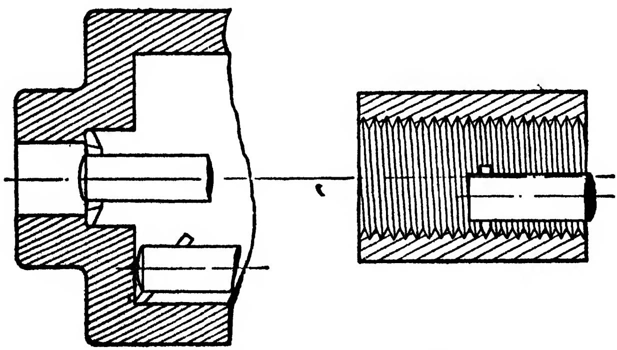


FIG. 205.—Boring Bar Examples.

bar, and one side of it is split in order that the bar can be gripped when the set screw is tightened down.

Illustrations showing the use of the tool bar, and the form the cutters take, are given in Fig. 205. Boring tools

afford another example of the specially economical effect of using tool-holders. They save the time taken for re-grinding tools by the machine hand and prevent machincs from standing idle.

Combined Turning and Boring Tool-Holder

A combined turning and boring tool-holder is shown in Fig. 206. When using the turning tool, an adjustment

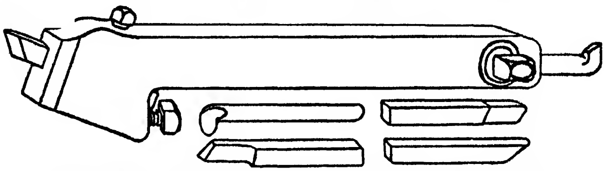


FIG. 206.—Combined Turning and Boring Tool-Holder.

can be made by means of a small set-screw at the back. The boring tool is of round section, and when necessary can be turned to give the desired clearance.

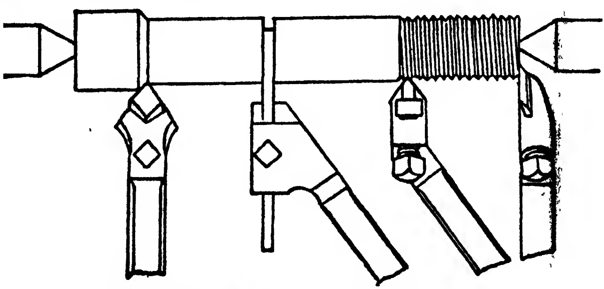


FIG. 207.—Application of Various Tool-Holders.

Tool-holders of various kinds are illustrated in Fig. 207. The tools are shown in position for facing, screw-cutting, parting, and turning.

Cemented Carbide Tipped Tools

The tool-holders as given at Figs. 192-207 are suitable for small sections of plain carbon and the alloy tool steels, also Stellite, but they are of little use for the cemented carbides. This is due to two factors: (1) the brittleness of the carbides; (2) the smallness of the tips and their high cost. Hence the usual method of holding tips of this type in position is by hard-soldering them to a suitable steel shank, using either silver solder or a copper alloy, and heating the parts with an oxy-acetylene flame, or by an electrical resistance. In order to give the tip the maximum support the shank should be machined to take the cutting thrust and to give the required cutting angle. On occasions a holder similar to Fig. 200 may be used, but care should be taken to ensure that the carbide is firmly gripped on the two faces.

CHAPTER XI

LATHE TOOLS, SPEEDS, AND FEEDS

SUCCESSFUL and accurate turning can only be accomplished by the use of lathe tools of correct shape, ground to the most suitable angles for the metal being cut, and used in a correct manner. The contour of a cutting tool will depend upon the shape required on the component. The cutting angle depends upon the material to be machined, which has great influence upon the rake and clearance angles.

A complete set of single-point cutting tools, as made by Messrs Edgar Allen & Co. Ltd., Sheffield, is illustrated at Fig. 208 and are used on all classes of lathes, shapers, and planers. They are of the composite type, having the cutting portion of a tungsten cobalt high-speed steel butt welded on to a medium carbon-steel shank. In this way a great economy is made in the use of the expensive alloy steel and at the same time a tool having a strong cross-section is obtained. The base of each tool is ground flat so as to ensure that it will bed down satisfactorily when clamped in the tool post.

Hints on Grinding

The regrinding of single-point cutting tools, whether of the solid or welded type, is simple. Dry grinding using a free cutting wheel is strongly recommended, the reason being that wet grinding of high speed carries with it the risk that the operator may make too long and too hard a contact with the wheel face. Such a procedure gives rise to local heating of the tool face subjected to the grinding

treatment, usually the centre, where the coolant cannot reach in such quantities as to keep the material cool. Then, as the tool is withdrawn from contact with the grinding wheel, the water immediately impinges on the hot spot. The sudden quenching of the locally heated area gives rise to a surface or grinding crack. Hence, when the tool is put into service, the cutting pressure and vibration cause the tool to fracture, and break down along the cutting edge.

No single-pointed cutting tool, when hot after use or dry grinding, should be dipped into cold water, for such a procedure is likely to cause cracking. One must always remember that the high alloy cutting material is very dense, and in order to avoid the creation of destructive contractional stresses, should be left in still air to reach room temperature. The slow rate of cooling in no way decreases the cutting efficiency; if this has already been reduced by incorrect grinding technique, rapid cooling after grinding will not restore the cutting edge to its former efficiency. A complete heat treatment is then essential for the alloy steels.

When a lathe is well designed, heavy, and very rigid, it contributes in itself very much towards its own general efficiency as a cutting tool. The value and usefulness of a lathe depends almost entirely upon the amount of metal it will remove from a piece of work in a given time, consistent with a finish and accuracy as good and as near as required. However, even when a lathe is well designed, successful and accurate work can only be done when tools of proper shape, having correct cutting edges and proper clearances, are used.

The fact that the tools being used are all that can be desired is not, of course, the only requisite for rapid and accurate work. Speeds, feeds, depth of cut, tool hardness,

and the quality and nature of the metal being cut, are all factors which contribute towards the output and general efficiency of the lathe; but whatever the conditions and however good they may be, it is only possible to turn out satisfactory work when the tools are properly designed and correctly ground and fixed.

When studying the cutting action of lathe tools it is necessary to take into consideration the factors which go to make up a successful lathe tool. The action of the tool in cutting is similar to that of a wedge being driven into a piece of work at an angle; the more acute the angle of the wedge the easier it will penetrate, but only within certain limits, because if the wedge is too acute it will be insufficiently supported at the cutting edge and will either break off or turn over, and if it is obtuse it will be difficult to make it penetrate at all.

In the case of the wedge it is clear that the more acute the angle the easier the wedge will penetrate; this is true of the cutting angle of the lathe tool; but it is obviously necessary to support the cutting edge sufficient to prevent it breaking off or rapidly wearing away. The tool when in use must go on cutting for a considerable time, and therefore it must be well supported and backed up at the cutting edge.

Cutting Angle

The cutting angle depends first on the hardness and nature of the metal being cut, and then upon the amount of metal being removed. With cast iron, wrought iron, and steel, the harder the material the greater the cutting angle, also the heavier the cut the more the cutting edge must be supported by increasing the cutting angle. For brass and most of the bronze alloys the cutting angle requires to be greater than for ferrous metal, the top of the tool in most cases being left quite flat with the body of the tool.

With cast iron in particular the metal will be found to vary very much; some will be very soft, some extremely hard. The same thing applies to forging; here the same forging has hard and soft places, and sometimes the metal will be extremely hard and dirty on the surface. Gun-metal and bronze also range between very soft metal and extremely hard metal.

In spite of the varying nature of the different metals the tendency of modern practice is to have the lathe tools ground by the tool-room department and not by the turner. Repetition work, the improvements that have been made in the foundry and smithy, and the advance in the knowledge of metallurgy, have made this to a great extent possible.

While it is not possible to give exact cutting angles for tools to be used on the general lathe, the angles given in Fig. 208 will serve as a guide, and can be taken as being approximately correct.

A considerable amount of practical experience will be found necessary before it is possible to decide upon the most suitable cutting angle and rake for the different classes of jobs commonly met with in the repair and general shop.

Height of the Tool

In turning any description of work, or any particular metal in an ordinary lathe, the correct position of the tool is for the cutting edge to be at the same height as the point of the lathe centre. The fact of the tool being a little high or low when turning a piece of work of large diameter is not of great importance; but when turning very small or taper work it is of the utmost importance,

and unless quite correct, will give bad results. This applies in all cases for all types of tools and all classes of metals. The correct position for a tool is shown in Fig. 209. It should be quite flat on the holder and level with centre when held down; the effect of raising the tool above the centre will be seen in Fig. 210. Here the clearance is decreased, causing the front of the tool to rub on the

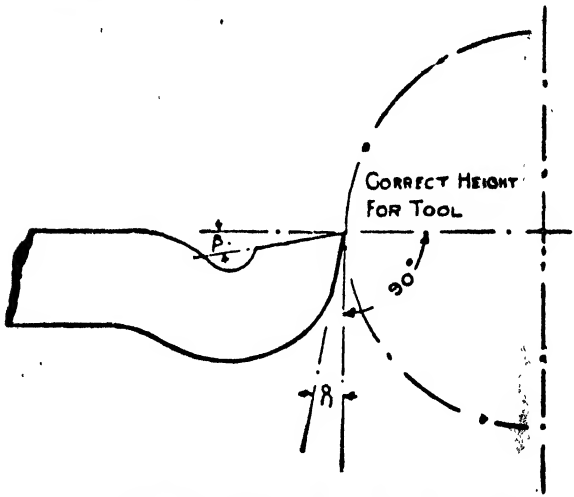


FIG. 209.—Correct Position for Lathe Tool.

work, and the top rake is increased, making the point of the tool weak and liable to break off; lowering the tool, as in Fig. 211, also has a bad effect, as it considerably increases the front clearance and at the same time takes away the top rake, so that instead of the tool cutting as it should do, it simply grinds away rapidly at the point.

If the cutting edge of a tool is found to be above the centre of the lathe when it is laid on the tool holder, then

the tool is unsuitable for use in that lathe; if, on the other hand, the cutting edge is below the centre, it can be packed up to the correct height without any detriment, provided the packing is parallel and extends the full length of the tool and not at either of the ends.

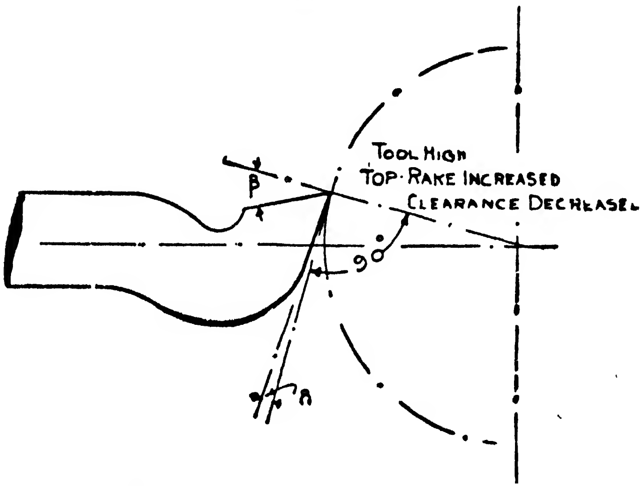


FIG. 210.—Incorrect Position for Lathe Tool.

Tool Contour in Plan

The contour of a cutting tool taken in plan is determined by the shape required on the finished workpiece or the operation performed. This is clearly shown by the various types of tools as feature at Fig. 208.

Top Rake

The top rake of any cutting tool, excluding the form tool, is determined solely by the class of material to be cut. Soft material such as mild steel would have a top

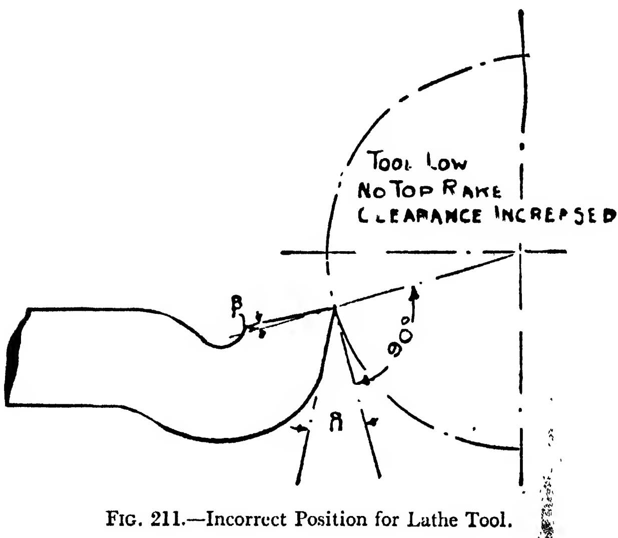


FIG. 211.—Incorrect Position for Lathe Tool.

rake of around 15° and aluminium, say, 40°, but with the harder materials such as the high tensile steels it is essential to reduce the angle to around 5°.

When brass is being turned it is not usual to give any

top rake, as with the peculiar nature of this metal all the turnings will be removed in the form of short chips.

Side Rake

It is impossible to give any definite figures as to the side rake required on a single point cutting tool as much depends upon the material to be cut, the class of cutting media chosen, H.S.S. or a cemented carbide, plus the fact that the rake of the tool measuring normal to the cutting edge must be such as to give a strong section. In all instances the best policy is to follow those recommended by the manufacturers of the cutting material or listed in a work dealing specially with metal cutting tools.

Front Clearance

The question of front clearance is a comparatively simple one. Front clearance is the angle formed by the front of the tool and a line drawn at a tangent to the work at right angles to the centres. For hard ferrous metals the clearance is kept as small as possible in order to well support the cutting edge, but so as to just prevent the front of the tool, below the cutting edge, rubbing on the work. For mild steel and wrought iron the clearance is increased in order to obtain a more acute cutting angle. This, of course, is possible, because the metal being comparatively soft, the tool will stand up to the work with less support than would be necessary with a harder metal.

Generally the front clearance may be taken on the following basis:—

Mild and medium carbon steel, aluminium and its alloys	10°
Steel between 35 and 55 tons, soft brass and copper, soft cast iron	8°
Steel over 55 tons, hard non-ferrous alloys	5°
Hard cast iron and its alloys	3°

Side Clearance

The side clearance of a lathe tool must be considered in relation to the feed. The amount given is usually about the same as for front clearance, but when a coarse feed is being used it may be necessary to grind a side clearance to allow for the resulting tool advance.

Direction of Feed

In most cases the movement given to the tools is from the tailstock to the fast headstock, and the majority of tools are designed upon this basis. When, however, it is desired to feed with the ordinary tool from left to right, the rake and clearance angles must be adjusted to meet the new conditions.

Holding the Tool

The support of the tool in the tool rest depends to some extent on the nature of the job, but in all cases, for roughing or heavy work, the closer the cutting edge is to the holding down plates the better, the tendency of having a firm tool being to stop chattering.

Roughing Tools

A type of roughing tool commonly used in repetition work in the modern machine shop is shown in Fig. 212. This class of tool is very successful when used in conjunction with a rigid lathe and when a plentiful supply of cooling liquid is applied to the tool nose.

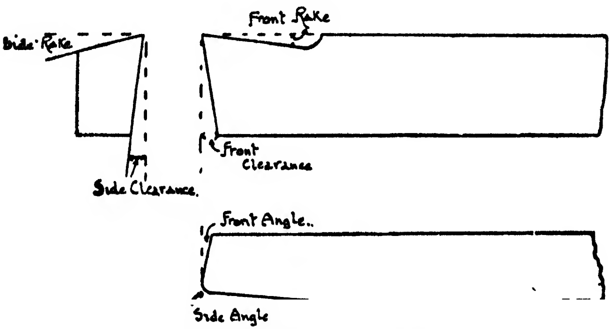


Fig. 212.—Lathe Front Tool.

be modified to suit the various degrees of hardness of metals, and also to comply with the different conditions which may exist:—

Material.	Front Rake.	Side Rake.	Front Clearance.	Side Clearance.
	Degrees.	Degrees.	Degrees.	Degrees.
Steel	10	12	8	6
Cast iron . . .	10	8	8	6
Wrought iron . .	15	15	12	6
Brass	0	0	12	12

Knife Tools

Knife tools for right and left hand cutting are represented in Fig. 208. These tools are easily forged and can be kept in an efficient state without difficulty. They are very useful tools, and in many cases can be made to take the place of the ordinary front tool.

Parting Tools

Very little top rake is given to this tool on account of the tendency for it to dig in. The chief point to notice is the side clearance. This should be sufficient to prevent rubbing and friction on the metal being cut.

Square Thread Screw-Cutting Tool

A good form of square thread cutting tool may be made from round bar. Care should be taken to ensure that the side clearances are satisfactory for the thread to be cut. In practice the side clearances have to be adjusted to suit the helix angle of the thread. Where surface grinding equipment is available it often proves better practice to make the tool from square or rectangular bar and grind the requisite clearances on the machine.

Boring Tools

A solid one piece form of boring tool is shown in Fig. 208. The cutting angle and profile of this tool is similar to that of the cranked front tool. The front clearance, however, must be sufficient to clear the inside of the hole. Many other types of boring tools are in use, the most convenient being those made from round or square section metal, the cutting tool being inserted at the end, and held in position with a grub or set screw.

Facing Tools

Right and left hand round nose facing tools are shown at Fig. 208. They are used on both the centre and turret lathe and have the top rake and clearance similar to the roughing tool shown at Fig. 212.

Spring Tools

The spring tool is used to produce a fine finish on work which does not require a great degree of accuracy. It takes a broad cut or scrape, and very little metal can be removed on account of its tendency to dig in. It is most useful for turning fillets and producing special forms. Before using the spring tool the metal should be roughed down nearly to size and shape.

Cutting Speeds and Feeds

The cutting speed of any metal depends upon its hardness, and it is very difficult to lay down any definite rule with regard to speeds and feeds, so much depending upon the quality of the tool steel and the size and rigidity of the lathe.

The feeds also depend upon the power of the lathe, and whether a roughing or finishing cut is being taken.

The following speeds can be taken as general workshop practice :—

Metal.	Cutting Speeds.
Wrought iron	35 to 130 feet per minute.
Mild steel	40 ,, 150
Hard steel	20 ,, 50
Brass - -	80 ,, 200
Cast iron -	30 ,, 80
Bronze -	35 ,, 80

When taking heavy cuts the usual practice is to choose a slow speed and a heavy feed ; conversely, when finishing it is usual to have a fine feed and high speed and this applies to all materials.

Cooling Tools and Work

The heating of lathe tools, and the consequent softening of cutting edges, can be reduced to a great extent by the use of a suitable cutting lubricant. In addition to keeping the tool cool the ample flow of the coolant keeps the workpiece cool and avoids distortion and expansion of material.

On lathes taking long and heavy cuts, it is usual to fix some form of pump that will deliver a steady and continuous flow of cooling liquid on cutting edge of the tool.

When taking a finishing cut a satisfactory surface and dimensional accuracy can best be obtained by using a suitable cutting lubricant in ample proportions so that both the tool and workpiece are maintained at a temperature close to that of the room.

Carefully carried out experiments have demonstrated that when roughing with a heavy feed and using high-speed tools an adequate flow of a suitable cutting compound will permit a higher speed for the same tool life, or alternatively give a longer tool life at the same speed. With a chip, say, .035 in. thick and .25 in. long the value of the lubricant is such that the speed may be increased roughly 50 per cent.

jobs and repair work it may on occasions be found useful.

Work having holes of larger diameter than about 4 in. is frequently turned on mandrels similar to that shown

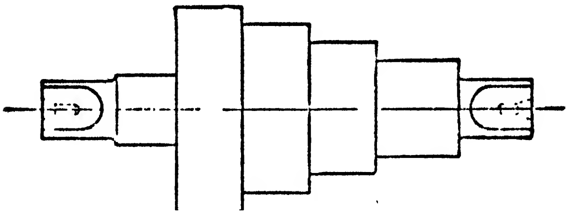


FIG. 215—Step Mandrel.

in Fig. 216. Here the collars, which are solid with the body, can be made either parallel or of different sizes to suit the work. By using a mandrel of this description, considerably less weight of material is required. It generally

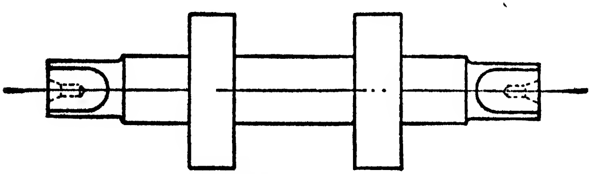


FIG. 216.—Collar Mandrel for Large Work.

fits better than a solid mandrel, and the object desired is obtained in a satisfactory manner.

Odd jobs having large size holes can be turned on solid wood mandrels. A suitable piece of hard wood turned to size and tightly driven into the work will be found quite suitable for any comparatively light job. The wood mandrel is quickly prepared. It can be driven or

pressed into position without much fear of cracking the work, and is of considerably less weight than the metal one.

Screw Mandrels

Two different kinds of screwed mandrels are shown in Figs. 217 and 218. This type of mandrel is required

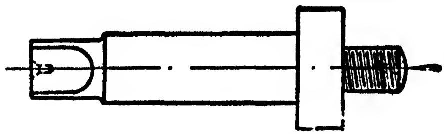


FIG. 217.—Screwed Mandrel.

when turning work having a threaded hole. They can be made with V or square threads, and can be right or left handed, as necessary. In the former example the work is held in position by simply screwing it on and

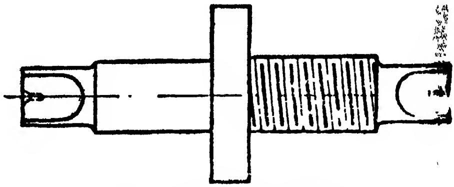


FIG. 218.—Threaded Mandrel.

letting it come up against the turned shoulder, while in the latter it can be additionally secured by means of a washer and nut. By allowing the work to project beyond the end of the thread, the work can be faced without any possibility of damaging the screwed part.

Screwed flanges, collars, nuts, chuck and face plate backs and work of a similar description require mandrels of this type.

Cone Mandrels

Work having a hole bored to more than one diameter will often require a specially turned mandrel. In many cases, however, it is possible to use the double cone

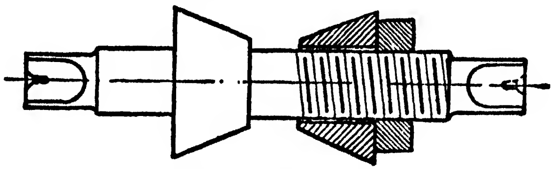


FIG. 219.—Double Cone Mandrel.

mandrel, shown in Fig. 219; and although there is a tendency to burr the outer edge of the hole, it will be found very convenient for certain classes of jobs. One of the cones is solid with the mandrel, and the other is tightened on to the work by means of a collar and nut; the tightening of the loose cone centres the work, and at the same time holds the work firmly enough to allow of its being turned.

A special form of mandrel is shown in Fig. 220. This is a screwed collar mandrel, and it is particularly useful for holding certain work which has been previously faced on both ends. The work is placed between the fixed collar or shoulder and the loose collar, the friction between the sides of the work and the collar being sufficient to allow the work being turned without shifting.

Brass bearings which have been sweated together are frequently held in this manner in order that light cuts can be taken off the outside without disturbing the two halves.

Expanding Mandrels

The objection to the solid or special type of lathe mandrel is its limited capacity; the bore of the work must be within a very few thousandths of the size of the mandrel, otherwise the work will not be firmly held. With repairs and odd jobs, where standard sizes are not the rule,

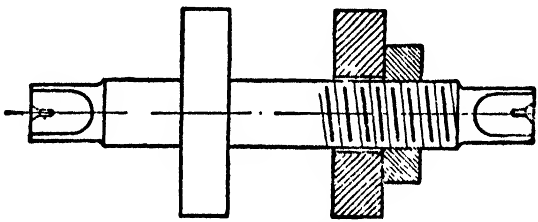


FIG. 220.—Screwed Cone Mandrel.

mandrels may have to be specially turned, and the making of a solid mandrel means a considerable amount of time and material; for those reasons the expanding mandrel is a time and cost saver for this class of work.

A very large number of different kinds of expanding mandrels are in use; some are simple in construction, others more complicated. The majority have only a limited range of holding power, but in most cases, with the addition of extra sleeves or blades, it is possible to cover a fairly large range of sizes.

The simplest type of expanding mandrel is shown in Fig. 221. This consists of a tapered spindle, fitted with a sleeve, parallel outside and tapered inside; the sleeve

is slit in one place its full length. The range is comparatively small, but still greater than that of the solid form of mandrel. It is necessary for the sleeve to just fit into the work, the expansion being obtained by driving in

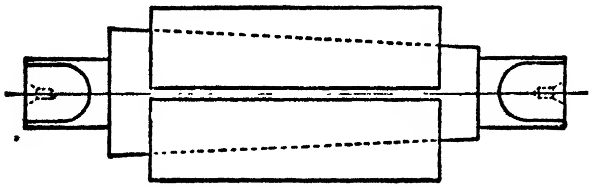


FIG. 221.—Expanding Mandrel.

the spindle, when the sleeve is in position, by means of a copper or lead hammer.

Sleeves of various sizes can be fitted to the spindle, and thus a considerable number of different sizes of work can be firmly held. One advantage with this type of mandrel is that the sleeve can often be adjusted for position in the

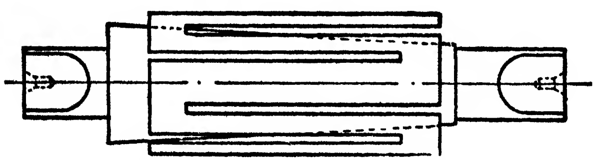


FIG. 222.—Expanding Mandrel.

bore of the work, so that the turner can run his lathe tool over the full face without damaging the mandrel.

Another type of expanding mandrel is shown in Fig. 222. It consists of a sleeve having a number of slits cut in it, and a tapered mandrel. The sleeve is inserted into the work, and the tapered mandrel is driven in with a lead hammer.

Special Mandrels

When some class of work has to be turned between centres it is necessary to adopt special methods of holding the work. A well designed and rigid lathe may be well adapted for a certain variety of jobs; but unless the mandrels or arbors are properly designed and efficient in action, the advantages of a lathe well adapted for rapid production are often greatly reduced.

The methods adopted in many works is for the turner to be given a job to do, the method to be used being left almost entirely to the man; if the job is an unusual one, the foreman may discuss the ways and means, but generally it is left to the turner. When the man is of long experience or particularly ingenious, the work may be held properly; but it is obviously unfair to expect the operative to decide on the most suitable method of holding the work at a moment's notice. When only one or two jobs are required, then improvised methods may be economical; but in the case of repetition work considerable attention and thought should be given to the question of supporting and holding.

The modern shop of large size is generally equipped with a tool planning or designing department. It is now recognised that in order to take advantage of modern tools it is necessary to have modern methods of holding work and tools, and to arrive at these modern methods it is necessary for the designers of tool and work holding appliances to be at least as up to date as the machine designer himself.

Expanding Bushings

A very common method of holding work having a finished hole is by means of expanding bushes. By this method it is possible to chuck the hole in a drilling machine, and still hold it in a given position on a mandrel

without obstructing the ends of the work, and in such a manner that both ends of the work may be faced. In the example shown in Fig. 223, the hole was too long to fit a split bushing the entire length, as the thickness of the bushing would have been rather excessive at the end, or else the taper would have had to be made too small. Therefore part of the mandrel is turned parallel and to fit the hole in the work; to determine that the piece of work is placed in the same position longitudinally each

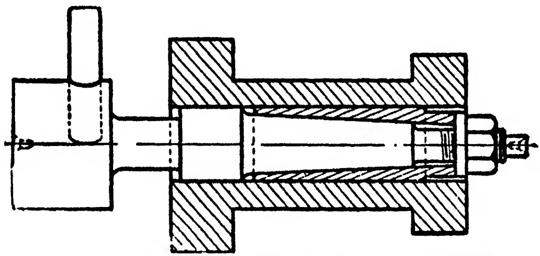


FIG. 223.—Special Type of Expanding Mandrel.

time a thickness gauge is used between the edge of the work and the side of the collar.

Supporting Thin Work

Some of the most useful holders for work to be machined in the lathe are those arranged to hold very thin work from the inside. An example is given in Fig. 224 of an arrangement for holding pistons which do not require grinding.

The usual method is to bore a hole for a short distance inward at the end of the piston and then drill the wrist-pin hole. The bored portion is used for locating the work in position by means of a stud through the wrist-pin. The

method shown permits the work to be done in one operation without any counterboring, and with the assurance of an even thickness of metal all around the piston. One end of the piston is centred in a centring machine. If the piston is heavy it may be held by the outside during this operation. If the metal is thin, it is preferable to centre it with reference to the inside, holding the work in a jig.

The holding device consists of three plungers A at each

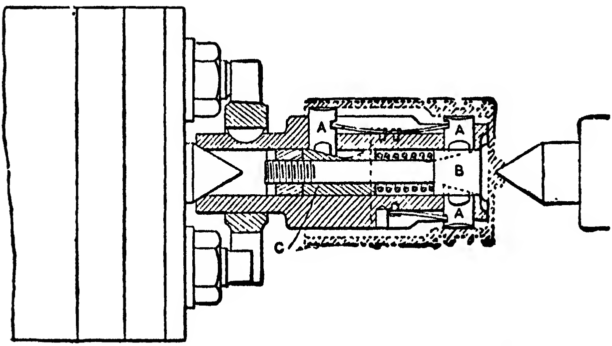


FIG. 224.—Mandrel Designed for Holding Pistons.

end of the piston, which slide in slots cut in the head of bolt B and in collar C, and which thus both centre the work and support it on the inside. In the case of small pistons only two plungers are used at the closed end, because there is not enough room for three on account of the bosses for the wrist-pin. The bolt with the tapered slot is tightened by means of a nut having a slot in it, which can be reached from the end of the arbor when the fixture is taken out of the machine, by means of a special screwdriver.

A method of holding a tapered bushing while finishing

the outside is shown in Fig. 225. The bushing is made in halves, and the hole is in the rough. It is necessary

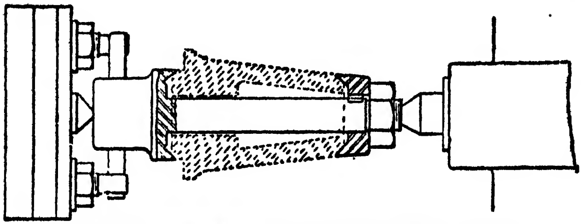


FIG. 225.—Special Mandrel for Holding Tapered Bushes.

that the joint between the halves should come exactly in the centre of the bushing so that the two halves may be interchangeable. The first operation is to face the joints; then the halves are clamped together and the ends are finished by a hollow mill to form a bearing for the clamping collars of the arbor.

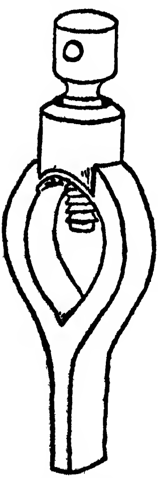


FIG. 226. Lathe Carrier.

Lathe Carriers

Work placed on a mandrel, or held between centres, has to be rotated. This is usually accomplished by means of a driving pin attached to a driving plate or a face plate, and a carrier or dog. The commonest form of carrier is shown in Fig. 226. The body part is large enough to slip over the work; it is then held in position by means of the screw bolt.

Another somewhat similar type of carrier is shown in Fig. 227, the only difference being in the screw, which is

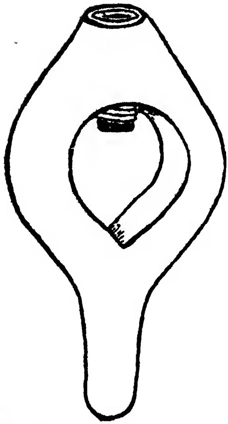


FIG. 227.—Lathe Carrier

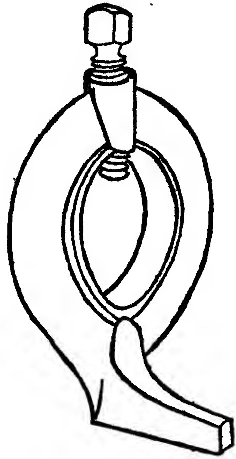


FIG. 228.—Bent Tailed Carrier

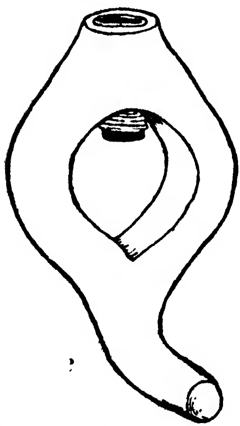


FIG. 229.—Bent Tailed Carrier.

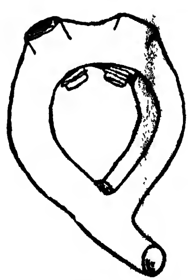


FIG. 230 —Large Bent Tailed Carrier.

this case does not project above the body of the carrier. It is to be preferred to the previous example, because the drive can only be taken by the tail of the carrier and not from the screw.

Two forms of bent tailed carriers are shown in Figs. 228

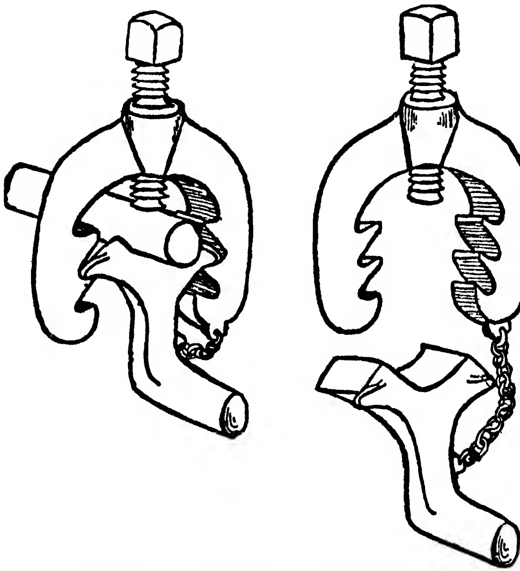


FIG. 231.—Adjustable Bent Tailed Carrier.

and 229. These require a slot in the face plate or driving plate, to receive the bent end of the carrier.

A carrier used for holding large diameter jobs is shown in Fig. 230. This is also bent tailed, and is provided with two grub screws for securing it to the work.

An adjustable form of carrier is shown in Fig. 231. This can be made to take a large range of diameters, and

thus one carrier will do the work of several of the solid kinds.

A hinged design of lathe carrier is shown in Fig. 232. The body is made of two steel castings; the serrated gripping parts are hardened cast steel, and the other parts

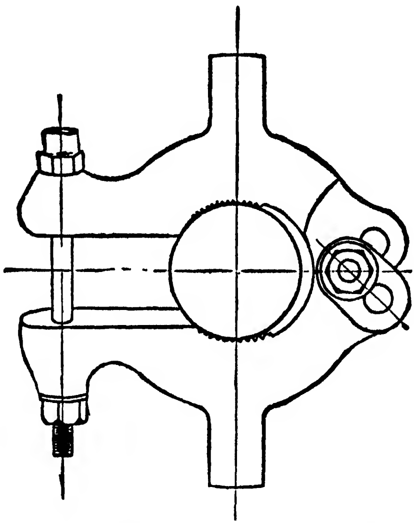


FIG. 232.—Hinged Type of Lathe Carrier.

are mild steel. Three sizes of these carriers are made; one takes 2 in. to 4 in., one 3 in. to 6 in., and the other $5\frac{1}{2}$ in. to 9 in.

A light form of adjustable carrier is shown in Fig. 233. This is very useful on light work, as the sides are balanced on each side of the centres.

When finished work is held by means of a carrier, a

screws or bolts should be sunk beneath the surface so that there is no danger of the operators clothes or fingers being trapped as the chuck is rotating.

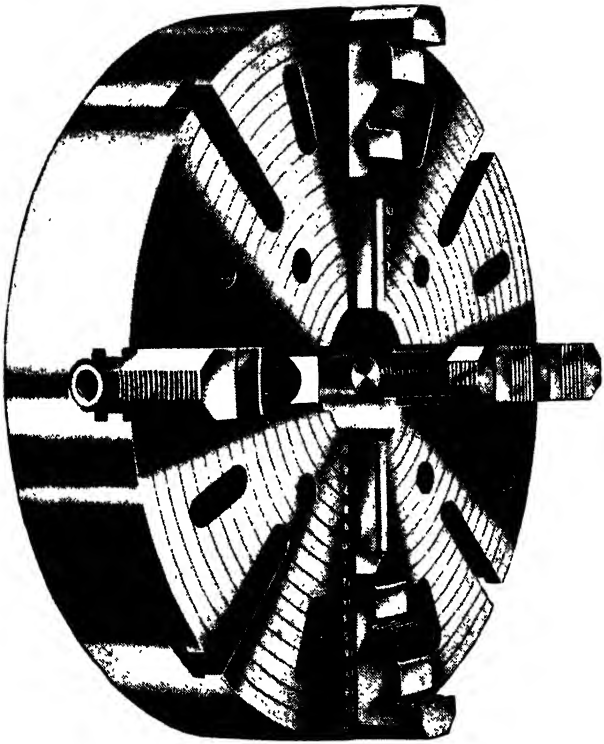


FIG. 234.—The Four-Jaw Independent Chuck.

It is important that every care should be taken to machine and mount adapters accurately. This is not always a simple matter.

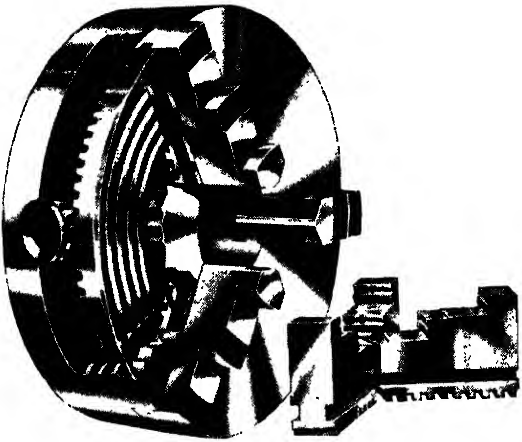


FIG. 235.—The Three-Jaw Self-Centring Chuck.

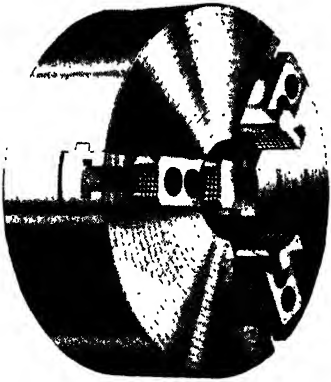


FIG. 236.—Three-Jaw Concentric Chuck with Detachable Jaws.

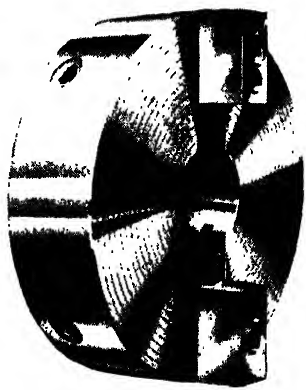


FIG. 237.—Two-Jaw Concentric Chuck having Detachable Jaws.

If the spindle has a plain parallel part at the end of the thread as shown in A, Fig. 240, test this for perfect truth, also test the face of the spindle flange at B. Cut the thread in the adapter an easy fit on the spindle. If this is done, the parallel fit between the spindle and the adapter

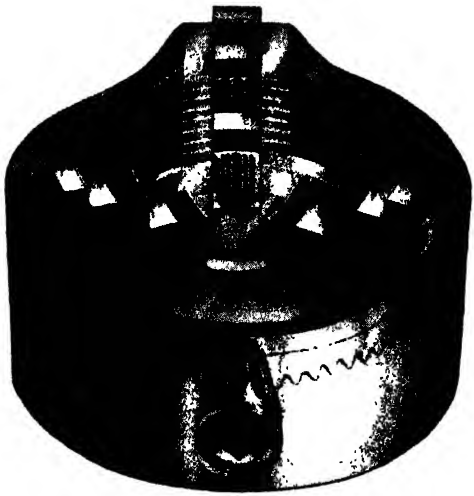


FIG. 238.—Taylor Three-Jaw Self-Centring Chuck.

will maintain the accuracy, the thread only having to hold the adapter on. If the thread alone is relied upon, it is impossible to maintain perfect accuracy.

It is also very important that the face C, and the spigot D fitting the recess in the back of the chuck, should be finished when in position on the lathe spindle.

The flange C of the adapter must fit against the back of the chuck, and the spigot D must clear the bottom of the

recess as shown in Fig. 240. See that the face C is flat and test it on each side of the spindle by the method indicated at A and B, Fig. 240. The machine spindle may be oscillating and not facing flat.

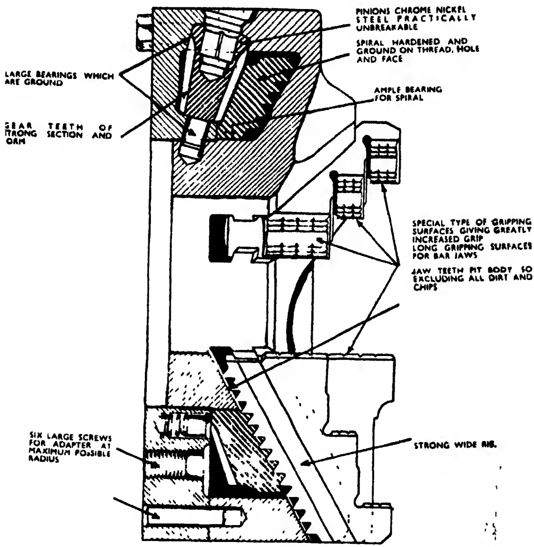
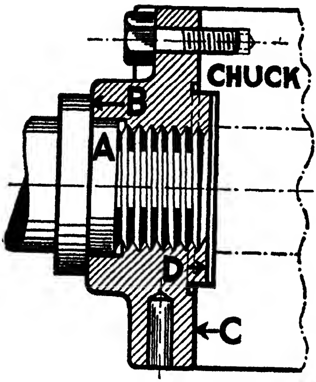


FIG. 239.—Cross-Section through Taylor's Self-Centring Chuck.
(*By courtesy of Messrs C. Taylor & Co. Ltd., Birmingham.*)

The screw holes in the adapter back plate should be drilled to ensure clearance.

See that the spigot is well on the recess before tightening up the bolts, otherwise the recess will be damaged and the accuracy of the chuck suffer.



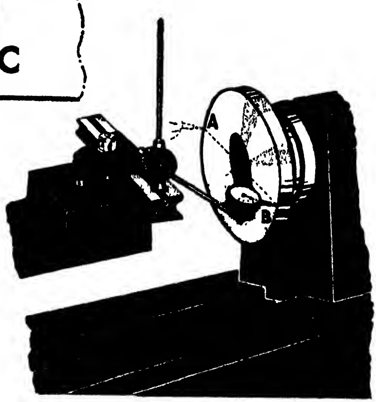


FIG. 240.—Back Plate for a Chuck and Checking the Truth when Mounted.

B

Face Plates

The lathe face plate is a circular plate threaded to fit the nose of the lathe spindle, and faced perfectly true. Holes and slots are made in the plate by means of which work can be bolted and clamped in position.

Face plates fitted with jaws are adapted to a great variety of work, and are rapidly taking the place of the larger sizes of chucks. They are handier to use, and the jaws can be put on or off the plate without difficulty and without the use of blocks or help of any kind.

A face plate fitted with removable jaws is shown in Fig. 241. The advantage of this arrangement will be

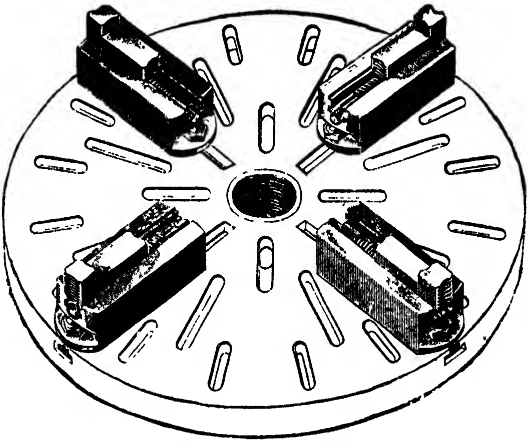


FIG. 241.--Face Plate with Removable Jaws.

apparent. The jaws, the sliding part of which can be run in or out and can be turned end for end, are reversible. At the end of the body is a recess for the nut, which allows them being used as face plates having tee slots.

The jaws which are shown in Fig. 242 have no rib on the bottom, but the holding-down bolts fill the openings of the slot in the face plate. If the openings in the plate are very narrow, a small section of the bolts may be machined to fit, while if the openings are unusually wide, collars can be fitted to the bolts.

Magnetic Chucks

With many components the question of holding during the machining operation presents no difficulty, yet occasions do arise when either size or shape of an article is such that the standard equipment as mentioned above proves unsuitable. Under these conditions, and providing

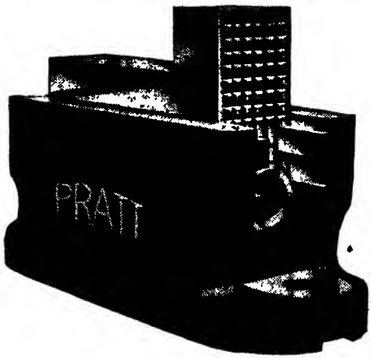


FIG. 242.—Jaws for a Face Plate.

that the article is made in some magnetic metal, it may be possible to choose the magnetic chuck. In practice one will find that this class of equipment is divided into two groups: (1) the non-electric chuck, and (2) the power-operated chucks the magnets of which are energised by means of an electric current taken off the supply mains.

Both groups of electric chucks are made in a wide range of types and sizes and may be designed to suit specific machining problems. The use of such equipment is wide and magnetic chucks are chosen when marking out, holding parts on the bench for filing, on the lathe,

shaper, planer, miller, and grinder. Fig. 243 illustrates a small-sized chuck by Messrs J. H. Humphreys & Sons of Oldham, as is fitted to a lathe and the generally accepted method of connecting the chuck to the power supply. By running the cable through the hollow spindle of the lathe to the small collector rings at the opposite end enables the use of a good supply of a cutting lubricant to be used without any fear of the liquid, grinding dust, or dirt

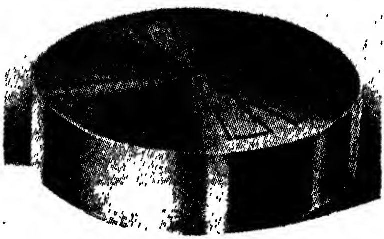
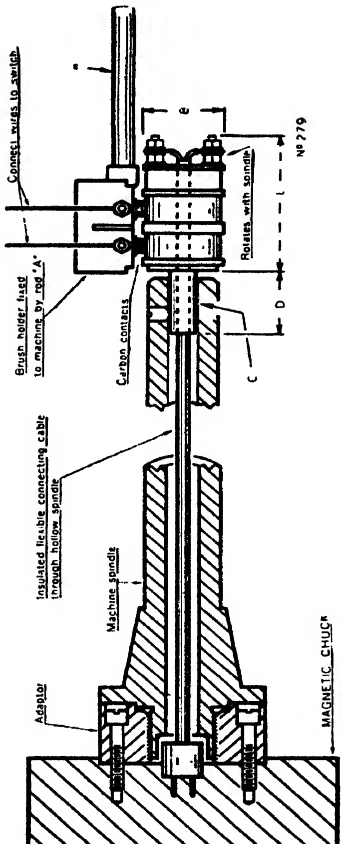


FIG. 243.—Circular Magnetic Chuck.
(By courtesy of Messrs J. H. Humphreys & Sons, Oldham.)

making contact with the "live connections." Of course there are other wiring arrangements, the general layout being adjusted to suit the known operating conditions.

Fig. 246 illustrates a rectangular type of non-electric magnetic chuck by Messrs James Neill & Co. Ltd., Sheffield, and this class of chuck is used for marking out various types of bench work on the shaper and grinder. To energise the magnets one simply moves the small lever through 180°, and as there are no electrical connections to make, one may carry the chuck from the machine to the bench or marking-out table without difficulty.



FIGS. 244-45.—Magnetic Chuck Electrically Operated for a Lathe, etc., and Connections.

(By courtesy of Messrs. J. H. Humphreys & Sons, Oldham.)

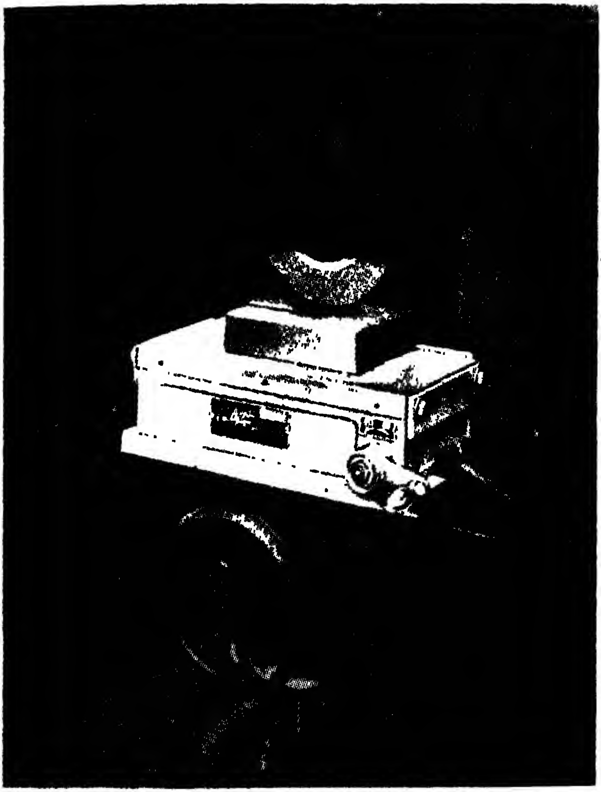


FIG. 246.—Surface Grinder using a Non-Electric Magnetic Chuck.

(By courtesy of Messrs J. Neill & Co. Ltd., Sheffield.)

When a steel article has been removed from a magnetic chuck after a machining operation it is highly probable that a residue of magnetism is retained in the material. In some instances this can prove very troublesome. Hence the need on a wide range of engineering equipment to withdraw all traces of magnetism from the article, and this is done by passing the article over or through a demagnetiser, a small type of which is shown in Fig. 247.

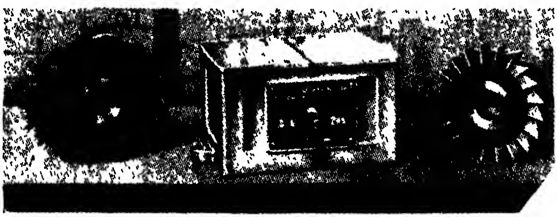


FIG. 247.—A Demagnetiser and Examples. Cutter before and after demagnetisation.
(By courtesy of Messrs J. Neill & Co. Ltd., Sheffield.)

Steadies

When long or slender shafts are being turned, or long screws cut, it is necessary to support the work in one or more places in order to prevent it springing, and for this purpose steadies are used. These may be fixed or moving. Fig. 248 illustrates a form of fixed steady; it is bolted to the bed of the lathe, the supporting arms being adjusted to just touch the work, which is turned at the part where the arms touch or rub. The top part of the steady is hinged, and can be lifted when it is necessary to remove the work.

A revolving steady with a fixed base is shown in Fig. 249; these are extremely useful, as they will take rough work not previously machined, and are capable

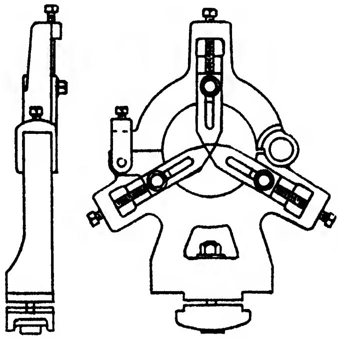


FIG. 248.—Three-Point Steady.

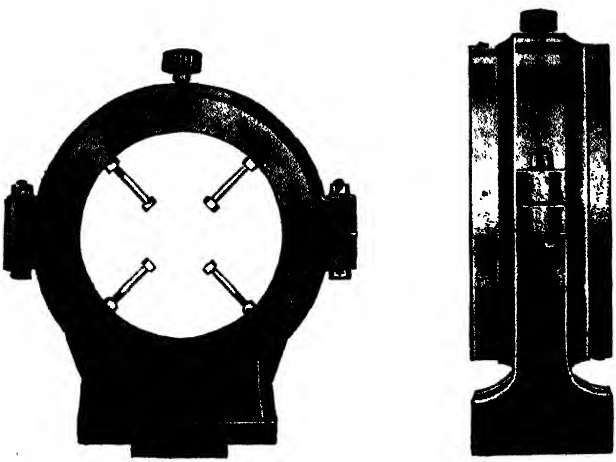


FIG. 249.—Revolving Steady.

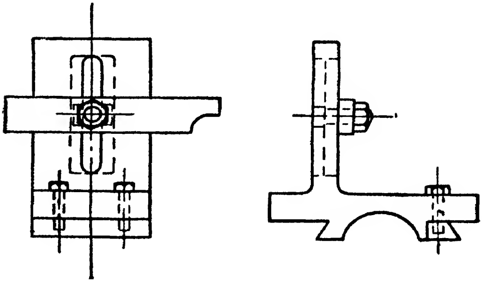


FIG. 250.—Travelling Steady.

FIG. 251.—Three-Point Travelling Steady.

of gripping round or square section work. They are particularly useful for work overhanging the lathe chuck, and where the application of the lathe tailstock is impracticable, such as facing and screwing pipes and flanges and boring the ends of spindles.

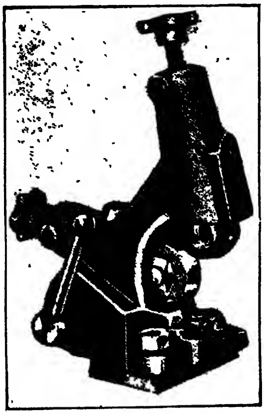


FIG. 252.—Travelling Steady with Rollers.

Travelling Steadies or finger steadies are attached to the lathe carriage and move with the lathe tool. The finger piece of the steady shown in Fig. 250 is adjusted to just touch the work, and should be arranged to fit on the right-hand side of the tool, if cutting from right to left.

Another type of travelling steady is shown in Fig. 251; this is provided with three points of adjustment, and

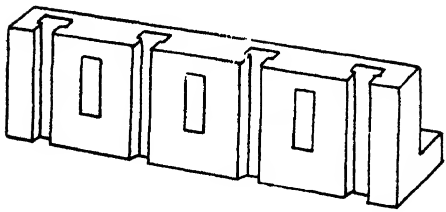


FIG. 253.—Plain Angle Plate.

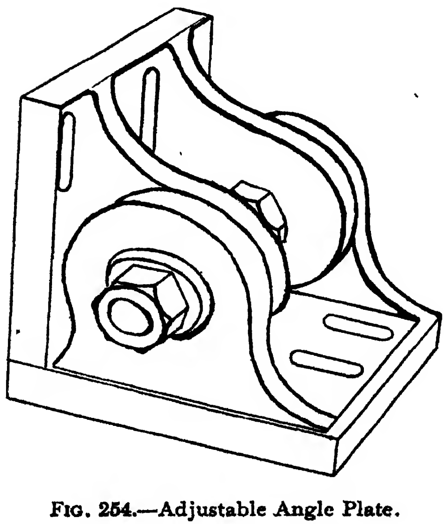


FIG. 254.—Adjustable Angle Plate.

answers its purpose very well. A somewhat similar type is shown in Fig. 252; here rollers are fitted in place of the finger pieces, and with this less friction is set up between the supports and the work.

Angle Plates are frequently used in conjunction with the face plate. They are useful for facing or boring work where two or more faces are at right angles to each other. The angle plate shown in Fig. 253 is simply a cast-iron plate with two faces planed at right angles to each other, and having slots in various positions for taking clamping bolts.

An adjustable angle plate is shown in Fig. 254; with this it is possible to hold work at other angles besides the right angle. It will be found particularly useful on certain classes of work.

CHAPTER XIII

TURNING

Preparing Work

Preparing Work.—All work that is to be turned between lathe centres must be first properly prepared by correctly centring it. Several methods may be used to locate the centre, and it depends upon the shape and size of the work as to which is the best method to adopt. For cylindrical work it is usual to place the work in vee blocks, and find the centre by means of the scribing block or surface gauge. In other cases it is more convenient to use the dividers, or a pair of hermaphrodite calipers, the object being to obtain four small arcs an equal distance from the outside.

When the approximate centre is obtained, a mark is made with a centre punch, and the work is revolved by hand between the centres of the lathe and tested for truth. If found to run out of truth, one or both centre marks must be drawn over in the direction required, and when running quite true the centre holes may be drilled.

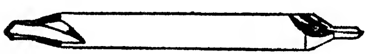


FIG. 255.—Centring Drill.

For this purpose a centre drill, as shown in Fig. 255, is generally used; this drills and countersinks at one operation. If an ordinary drill is used, the hole must afterwards be countersunk with a drill ground to an angle of 60°. The size of the centring hole depends upon the size of the work. For small light work a hole $\frac{1}{16}$ of an inch in diameter, and countersunk 60°, would be large enough.

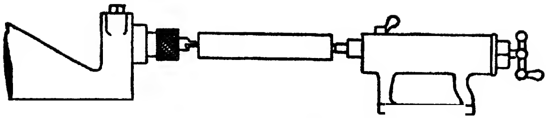


FIG. 256.—Holding Work for Centring.

Drilling Centre Holes.—In the absence of a special centring machine, the work to be drilled can be held up against the tailstock centre of a small lathe and drilled, as shown in Fig. 256. Another accurate method of drilling up the ends of work is shown in Fig. 257; in this case a centre is placed in the hole generally found in the centre of the drilling machine table.

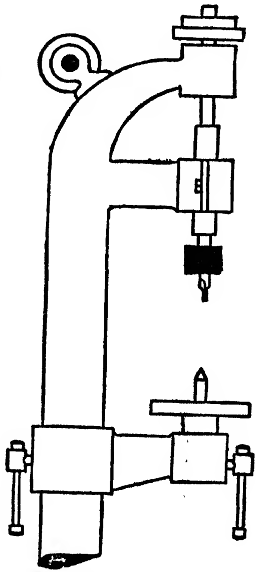


FIG. 257.—Centring Work on Drilling Machine.

A widely used method of preparing the work for the centres is to set the component true in a three or four jaw chuck and face the surface; note that on the second setting the facing brings the component roughly to length. With the article faced a drill chuck holding a centre drill is placed in the tailstock spindle. The position of the tailstock is then adjusted and the centre hole drilled to the required depth.

Square Centres.—When it is necessary to have the centres perfectly true with the outside of the work, the square centre shown in Fig. 258 can be

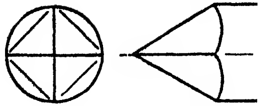


FIG. 258.—Square Centre.

used. This tool is placed in the end of the tailstock spindle, and the work is revolved, the bent bar shown in Fig. 259

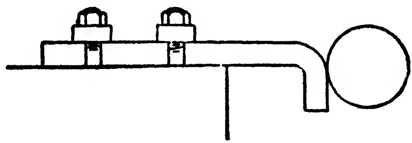


FIG. 259.—Square Centring.

being held in the slide rest, and then fed up to the work.

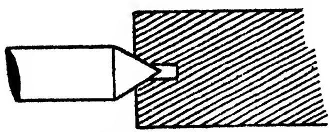


FIG. 260.—Correct Centre.

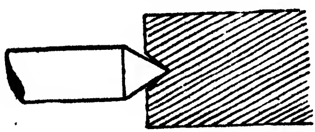


FIG. 261.—Countersink too large.

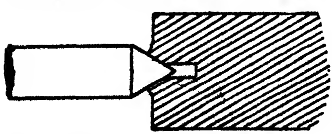


FIG. 262.—Hole not Countersunk.

It is very important that the centres of work to be turned in the lathe should be countersunk to an angle corresponding exactly to the angle of the lathe centres. In Fig. 260 the centre of the work is correct and exactly conforms with the lathe centre, the hole forming a reservoir for oil. In Fig. 261 no hole has been drilled, and the countersink is of greater angle than the centre, the result being that the work is being held on a point only, and will not run true for any length of time. In

Fig. 262 the hole was left uncountersunk, and consequently the tailstock centre required constant adjustment, the metal at the end of the work being pushed up and forming a burr.

Order of Procedure.—The following order of procedure should be carried out when turning between centres:—

1. Select a suitable carrier and arrange for it to be driven from the tail of the carrier, as shown in Fig. 263. Before placing any work between centres, put a little oil on the live or moving centre, and then adjust the back centre by means of the tailstock, and afterwards by means of the tailstock spindle, screwing it in or out, so that the work will revolve quite freely without being slack, and at the same time allowing sufficient room for the saddle or top slide rest to move the required amount. In adjusting the spindle, it should be kept as short as possible to obtain rigidity.

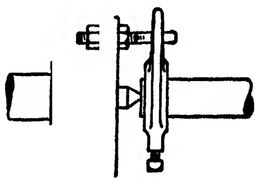


FIG. 263.—Driving Plate.

2. Next select the tool, and secure it in the tool holder with the cutting edge exactly on a level with the lathe centres.

3. Determine the speed and feed, and make the necessary adjustments to gears and belts.

4. Next try the lathe, by moving the cone driving pulley round one or two revolutions, and make sure everything is quite clear and secure.

5. In order to give a true datum and to prevent unequal wear of the conical bearing surfaces of the centre holes, face both ends true, and if possible to, say, length plus $\frac{1}{32}$ in. Then rough turn the diameter or diameters. If there should be an excess of material on the length, the depth of the centre hole should be such that the need for

re-centring does not arise, and when facing a "tit" should be left on each end for removal after roughing.

6. After rough turning skim both faces, thus bringing the article to length; finish turn to size.

Mandrels.—The best class of mandrel is made from steel, correctly centred, hardened, and ground accurately to size. They are provided with flats at both ends to prevent the set screw of the driving carrier from slipping when being driven in the lathe.

Mandrel Work.—In order to use a mandrel it is necessary for the hole in the work to be slightly smaller

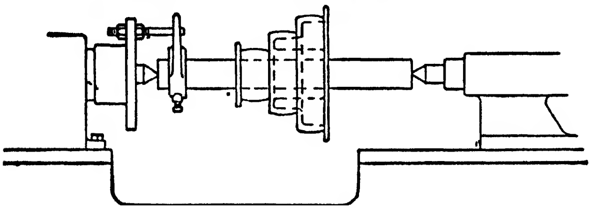


FIG. 264.—Mandrel Turning.

than the large end of the mandrel, and therefore the mandrel must be slightly tapered. An example of the use of the mandrel is shown in Fig. 264. In this case a three-cone pulley is forced on the mandrel and driven by means of a carrier.

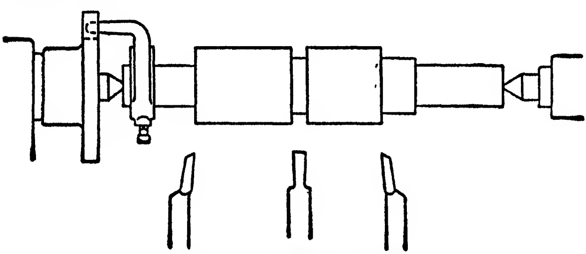


FIG. 265.—Plain Turning.

Plain Turning.—An example of plain turning is shown in Fig. 265. The front tool is used to rough down where possible, and the knife and parting tools are fed transversely to complete the work.

The Face Plate is a circular plate threaded to fit the lathe spindle, and faced perfectly true. Holes and slots are made in the plate, by means of which work can be bolted or clamped to it. In some face plate operations, such as boring, it is necessary to pack the work away from

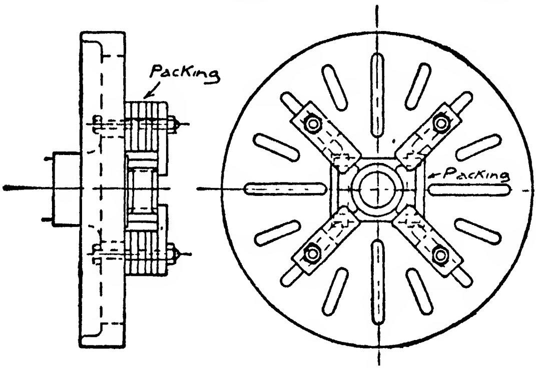


FIG. 266.—Boring Brasses.

the face of the plate by means of parallel strips, so as to allow the boring tool to pass right through the work. Fig. 266 shows a pair of brasses packed off from the plate with strips, and clamped down by means of four plates.

Balancing.—When the work placed on a face plate is more than a few pounds in weight, and is not revolving in the centre, a balance weight is bolted on the face plate in order to give a more even turning movement. The method is illustrated in Fig. 267, which gives an example of the use of an angle plate for holding a three-way pipe.

Taper Turning.—In the absence of a special taper turning device, taper turning can be accomplished either by setting over the centres, or by altering the slide rest. The method generally used is to alter the back centre by setting over the loose headstock in such a manner as to throw the back centre out of line with the fixed centre. By adopting that means, the self-acting mechanism can still be used, and the tool made to travel parallel with the lathe bed. As the amount of side adjustment is

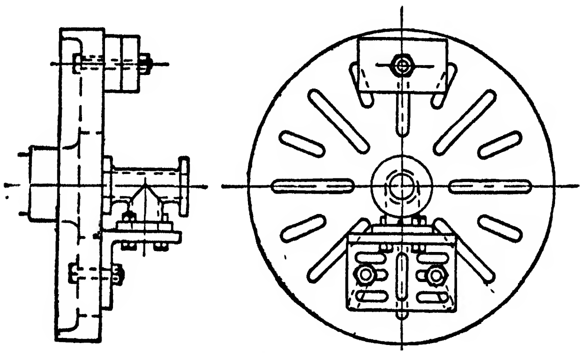


FIG. 267.—Using the Angle Plate.

small, only slight tapers can be turned in this manner, more especially when the work is of any length.

The amount the centre has to be moved over depends upon the amount of taper required, and the length between centres. If the back centre is set over 1 in., and the work is 4 ft. long, then it will be turned 2 in. smaller at one end than at the other, and this would give a cone half an inch taper to the foot. The objection to this form of taper turning is the unequal wear on the centre owing to the centres being out of line with each other.

The following rule applies to the set over of the loose headstock :—

$$\frac{\text{Length of work} \times \text{Taper}}{2} = \text{Distance tailstock is set out of centre line.}$$

Example.—Length of work, 4 ft. ; taper required, $\frac{1}{2}$ in. per foot.

Then, $$\frac{4 \times \frac{1}{2}}{2} = 1 \text{ in.}$$

Tailstock set over 1 in.

Taper Turning Attachment. — The illustration, Fig. 268, shows the attachment for turning taper, as is fitted to the Dean, Smith, & Grace lathe. It is strongly made, designed on correct principles, and contains several

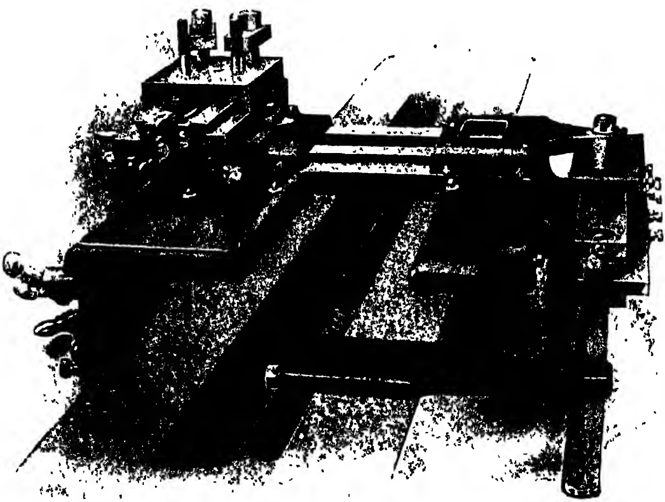


Fig. 268.—Taper Turning Attachment.

unique features. It is possible to easily change from parallel to taper turning, or vice versa, and as the taper attachment travels with the saddle, a taper can be turned anywhere in the length of bed. The guiding bar is graduated in degrees at one end, and in inches at the other, so that accurate adjustment can be quickly made,

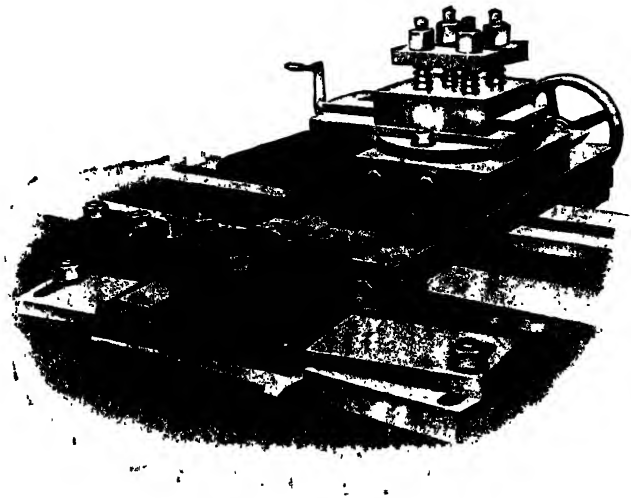


FIG. 269.—Taper Turning Attachment, by Messrs John Lang.

and tapers can be turned up to 9° from centre line of lathe.

Another taper turning attachment is shown in Fig. 269. This attachment allows the turner to have full use of the swivel slide, as the cut is put on and off by the saddle screw, thus doing away with the necessity of turning the swivel slide at right angles. The guide box is graduated at one end in degrees, and tapers may be turned up to an angle of 9° from the centre line of the lathe.

Tapers and Angles

Taper per Foot.	Included. <		With Centre Line.		Taper per Inch.	Taper per Inch from Centre Line.
	Deg.	Min.	Deg.	Min.		
1/8	0	36	0	18	·010416	·005203
3/16	0	54	0	27	·015625	·007812
1/4	1	12	0	36	·020833	·010416
5/16	1	30	0	45	·026042	·013021
3/8	1	47	0	53	·031250	·015625
7/16	2	5	1	2	·036458	·018229
1/2	2	23	1	11	·041667	·020833
9/16	2	42	1	21	·046875	·023438
5/8	3	...	1	30	·052084	·026042
11/16	3	18	1	39	·057292	·028646
3/4	3	25	1	47	·062500	·031250
13/16	3	52	1	56	·067708	·033854
7/8	4	12	2	6	·072917	·036456
15/16	4	28	2	14	·078125	·039063
1	4	45	2	23	·083330	·041667
1 1/4	5	58	2	59	·104666	·052084
1 1/2	7	8	3	34	·125000	·062500
1 3/4	8	20	4	10	·145833	·072917
2	9	32	4	46	·166666	·083332
2 1/2	11	54	5	57	·208333	·104166
3	14	16	7	8	·250000	·125000
3 1/2	16	36	8	18	·291666	·145833
4	18	54	9	27	·333333	·166666
4 1/2	21	14	10	37	·375000	·187500
5	23	32	11	46	·416666	·208333
6	28	6	14	3	·500000	·250000

Size of Standard Taper Pins

Taper 1/4 Inch per Foot

Number.	Largest Diameter of Pin.	Smallest Diameter of Pin.	Number.	Largest Diameter of Pin.	Smallest Diameter of Pin.
0	·156	·135	6	·341	·279
1	·172	·146	7	·409	·331
2	·193	·162	8	·492	·398
3	·219	·183	9	·591	·482
4	·250	·208	10	·706	·581
5	·289	·240			

Boring.—Work is sometimes cored, otherwise it is necessary to first drill a hole for the boring tool to enter. For this purpose a drill made from square section steel can be used, the body of the drill being held in the lathe tool holder, or a twist drill can be placed in the loose headstock spindle.

For boring purposes many different forms of boring tools and bars are made. Before adjusting the tool, care

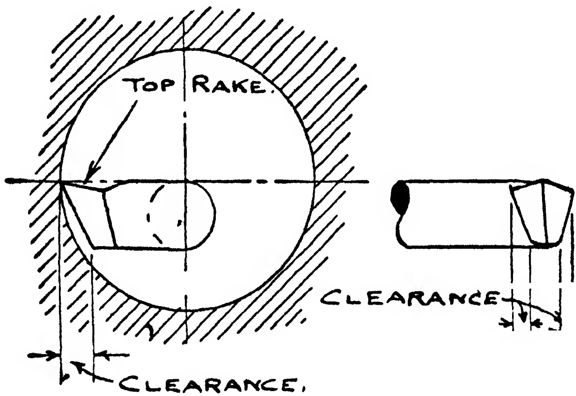


FIG. 270.—Position of Tool when Boring.

must be taken to have the tool ground to give sufficient clearance, so that the cutting edge is the most prominent part when set up in the lathe. The amount of top rake depends upon the nature of the metal being cut; if hard steel or brass, very little top rake can be given, but for wrought iron or mild steel a small amount of top rake will improve the cutting action of the tool. The correct height for all boring tools is when the cutting edge is level with the lathe centre, as shown in Fig. 270.

Jobs that are difficult to hold on the face plate or in the chuck, or which are too big to be swung in the lathe, are sometimes bored by means of a boring bar. To do this the top rests of the saddle are removed, and the work held directly on the saddle by means of bolts and plates.

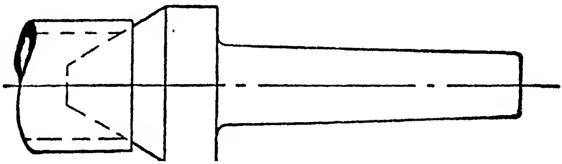


FIG. 271.—Pipe Centre.

The boring bar revolves between the lathe centres, the cut being made by feeding the saddle forward. Engine cylinders and pump barrels are frequently bored in the ordinary lathe by this means.

Pipe Work.—Wrought iron and steel tubes requiring turning or threading externally can be conveniently held

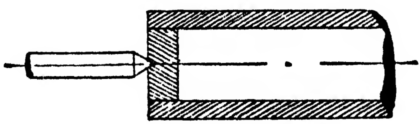


FIG. 272.—Method of Holding Tubes.

and driven between special large centres, as shown in Fig. 271. This arrangement will often be found suitable when turning flanges on pipes or taking cuts on the outside of small liners.

Another method of holding pipes or similar work is shown in Fig. 272. In this case an iron plug is turned

slightly tapered to fit the end of the work, suitable centres being made in the plugs. For the same purpose the

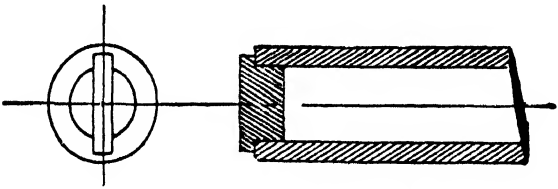


FIG. 273.—Method of Centring Tubes.

arrangement shown in Fig. 273 can be adopted; in this case a flange on the plugs prevents them from being pushed in the holes in the work.

CHAPTER XIV

SCREWS AND SCREW CUTTING

FORMS of screw threads vary according to the purpose for which they are to be used, and also according to the country in which they are manufactured. At the present time thread most frequently used in Great Britain for general engineering work is known as the Whitworth thread. In 1841 Sir Joseph Whitworth proposed the

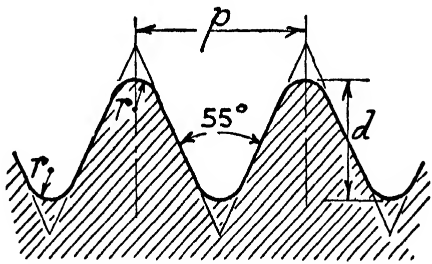


FIG. 274.—The Whitworth Thread Form.

adoption of a standard thread for bolts, and this system is chiefly used in Great Britain and a number of other countries.

The depth of thread is equal to 0.64 of the pitch, the top and bottom of the thread is rounded off one-sixth of the depth, and the sides form an angle of 55°.

Fig. 274 shows the form of thread—

The formula being $p = \text{pitch} = \dfrac{1}{\text{Number of threads per inch}}$.

$d = \text{depth} = p \times 0{\cdot}6403$. $\qquad r = \text{radius} = p \times 0{\cdot}1373$.

The British Association in 1881 adopted a system of screwed threads of small diameter. In this thread, which is only used for very small work, the thread angle is $47\frac{1}{2}°$, the depth 0.6' of the pitch; the top and bottom being rounded off two-elevenths of the pitch.

Fig. 275 shows the section of thread—

$$\text{The formula being } p = \text{pitch} = \frac{1}{\text{Number per millimetre}}.$$

$$d = \text{depth} = p \times 0{\cdot}6.$$

$$r = \text{radius} = \frac{2 \times p}{11}.$$

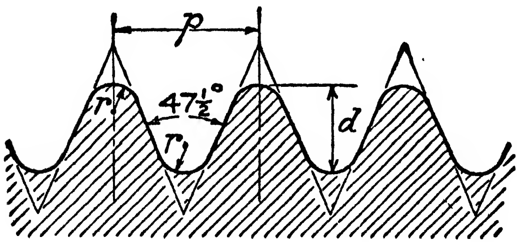


FIG. 275.—British Association Thread.

In the Sellers system of screwed threads the sides of the thread form an angle of 60°, and the top and bottom are truncated to form a flat one-eighth of the pitch.

This thread is shown in Fig. 276—

$$\text{The formula being } p = \text{pitch} = \frac{}{\text{Number of threads per inch}}.$$

$$d = \text{depth} = p \times 0{\cdot}6495.$$

$$f = \text{flat} = \frac{p}{8}.$$

The above forms of threads are termed vee threads, and are used where parts of work are to be firmly and securely fastened together, the chief consideration being

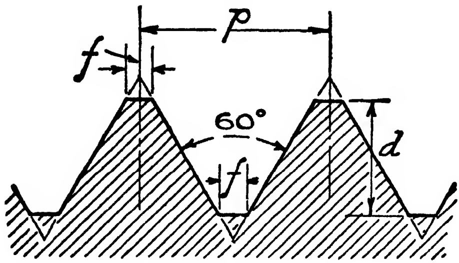


FIG. 276.—Sellers Thread.

power, strength, durability; where other questions are involved it is necessary to rely upon a different form of thread.

Where forces act in one direction only, the buttress thread is sometimes adopted. It has one surface normal

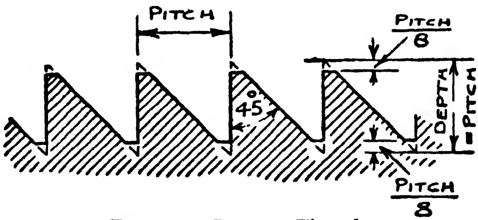


FIG. 277.—Buttress Thread.

to the axis, but the shearing strength is twice as great as that of the square thread.

A section of this thread is shown at Fig. 277.

There are a number of other standard thread forms and for these one should consult the relevant B.S.S.

Square Threads

Where it is necessary to obtain a quick travel or lead a square thread is often used. Theoretically, the depth and width of a square thread is half the pitch; in practice this is slightly modified to suit the pitch and lead.

Definitions of a Screw

Geometrically the screw is the union of a plane cylinder having a circular base and a projecting ridge, of uniform shape throughout its length, wrapped on the surface of a cylinder in a regular spiral.

Pitch is the distance a nut would travel in one complete revolution if the screw had a single thread, or the distance between the centre of one thread and the centre of the next, measured in a line with its axis.

Lead is a term used when considering multiple threads, and is the distance a nut would travel in one complete revolution, or the distance from the centre of one thread to the centre of the same thread allowing for one complete turn.

Inclination of a thread is the angle formed by each of its superficial elements of depth, with a plane perpendicular to the axis of the screw. This inclination increases in proportion as the axis of the screw is approached. The pitch, on the contrary, remained constant.

Multiple Threads

Where coarse pitch threads are necessary, in order to bring the size of threads within workable and reasonable limits, multiple threads are employed. The difference between a single and double thread is in the advance or spiral, the pitch or lead of a double start thread being

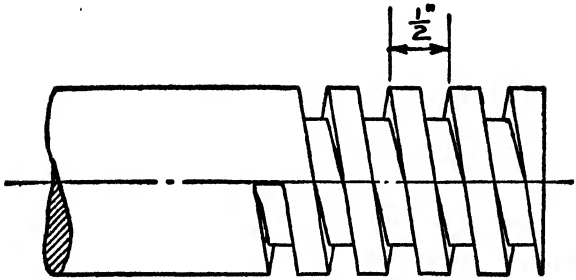


FIG. 278.—Right-Hand Square Thread.

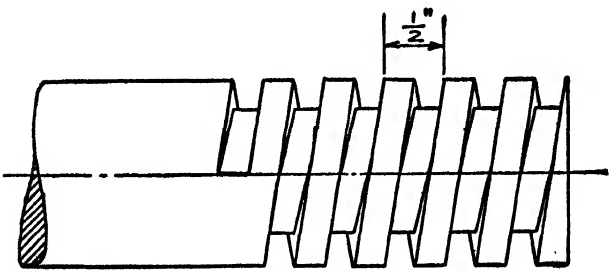


FIG. 279.—Left-Hand Square Thread.

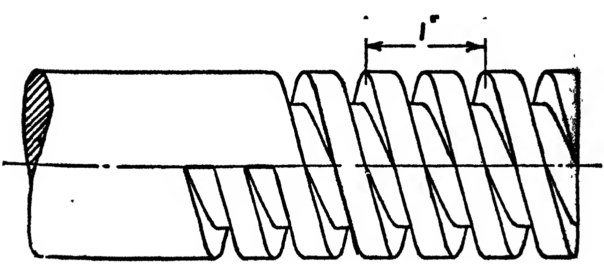


FIG. 280.—Double Right-Hand Thread.

twice that of a single start. Fig. 278 illustrates a single start right-hand thread of $\frac{1}{2}$ in. pitch, or two threads per inch; Fig. 279 shows the same pitch of thread, left hand; Fig. 280 shows a double start right-hand thread of $\frac{1}{2}$ in. pitch and 1 in. lead; Fig. 281 shows the same type of thread designed to give a triple start of $1\frac{1}{2}$ in. lead.

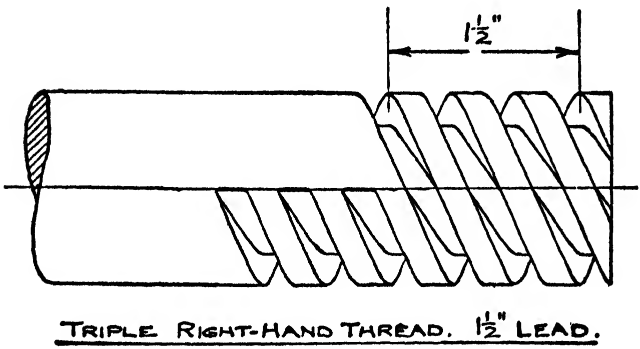


FIG. 281.—Triple Right-Hand Thread.

Right and Left Hand Thread

Screws may be made either right or left handed. A right-hand thread is one in which the nut must be turned in a right-handed direction to screw it on; a left-hand thread being one in which the nut would be screwed on by turning it to the left. Fig. 279 shows a left-hand thread.

Diameter of a Screw

The diameter of a screw is the measurement taken over the tops of the thread, and to obtain this measurement correctly it is often necessary to use special calipers having wide jaws.

To obtain the root diameter of a screw, it is necessary to use calipers having very thin jaws.

Measuring Pitch

The measurement of the pitch of fine threads is best accomplished by means of the screw pitch gauge, see Fig. 101, page 92. This is a tool having blades with notches of angular shape graded to the pitch stamped on the blade. The best form is that in which they can be used for internal and external testing. They are generally fitted with twenty or more blades, graded to measure between 9 and 40 threads per inch. If checking the pitch of a screw or ring gauge then equipment similar to that shown in Figs. 8 and 16, pages 17 and 29, would be used.

The Stock and Dies

Threads can be cut by several methods apart from the screw-cutting lathe.

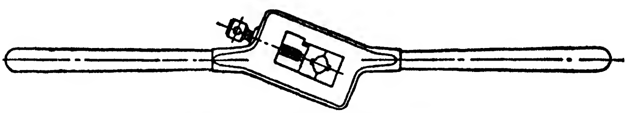


FIG. 282.—Stock and Dies.

For cutting threads on small work, where it is not convenient or necessary to do the job in the lathe, the stock and dies, Fig. 282, can often be used.

The stock is made from one piece of steel, the dies being in two parts, and usually fitting in a vee-shaped guide, being adjusted or screwed together by means of a set screw.

In using the stock and dies, the metal that is to be screwed is first turned to the exact diameter of the outside of the thread. The dies are then placed at the end of the metal and slightly tightened; they are then turned the

distance required, and then turned back. This process is repeated until a full-sized thread is cut.

In using the dies care should be taken to keep the clearance spaces clear, and when cutting iron or steel, to keep the metal well lubricated with oil. It should be remembered that dies cut in one direction only, therefore they should be only tightened up just previous to the cutting movement.

Dies for Gas Threads

Stock and dies for cutting gas threads or tubes are used to a far greater extent than the Whitworth dies.

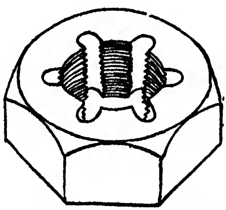


FIG. 283.—Hexagonal Die Nut.

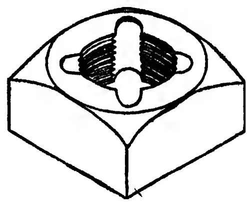


FIG. 284.—Square Die Nut.

With sizes below 2 inches it is usual to find a solid or one piece die used; above that size the split form of dies is more often used. In either case some form of guide is provided in order to keep the thread square with the axis of the tube.

Previous to using the gas dies it is necessary to grind or file the end of the tube slightly tapered, so as to allow the thread of the die to get a proper hold of the metal. With the solid form of die the thread is cut in one operation.

Die Nuts

A die nut is a solid form of die, made square or hexagon in shape to fit a spanner, Figs. 283 and 284.

They may have Whitworth or gas threads, and are chiefly used for running down the threads of studs or bolts, which have become burred up after being fitted in their place, and thus obviating the removal of the stud. They are particularly useful for running down studs in cylinder covers and slide-valve chests, and for use where there is insufficient room to turn the stock and dies.

Tapping

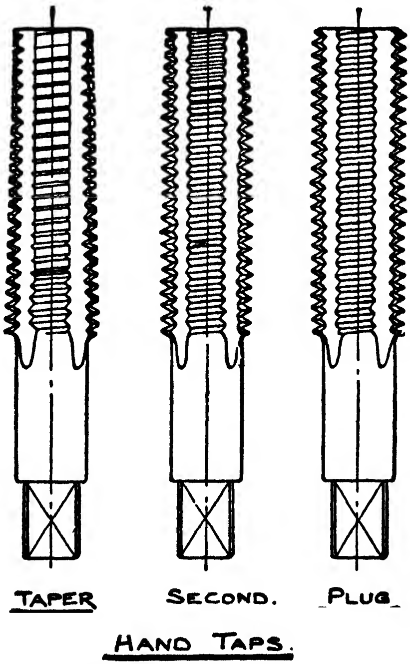


FIG. 285.—Set of Taps, Taper System.

Taps are used for cutting internal threads by hand or using a machine, and Fig. 285 illustrates a standard set of three hand taps. Normally, the parallel portion of each tap is cut to size. When tapping a "blind" hole by hand, the taper or number one tap is first taken to the required depth and then unwound out of the hole after which the chips are blown clear. Then number two tap is used, and this cuts a full thread a little deeper; finally, the number three or the plug tap is used to give the desired depth of thread. Given a "through" hole, each tap may be passed through the component.

To find the correct diameter of a drill for drilling a hole to give a full Whitworth thread, multiply the pitch of the screw by 1.28, and subtract the product from the outside diameter.

Example.—Find the size of a drill to cut a hole for tapping a 1-in. Whitworth thread. Then—

$$\text{Eight threads per inch} = \tfrac{1}{8}\text{ in. pitch} = 0{\cdot}125.$$
$$0{\cdot}125 \times 1{\cdot}28 = 0{\cdot}16.$$
$$1{\cdot}0 - 0{\cdot}16 = 0{\cdot}84 \text{ or } \tfrac{21}{25}.$$

Size of drill required $\frac{21}{25}$, the nearest standard size being $\frac{27}{32}$ in.

Taps for cutting square threads are occasionally made, but owing to inaccuracies caused during the hardening process they cannot be relied upon.

A small alteration of pitch in the vee thread would not be noticeable, and if a slight difference were made in the diameter of the nut and bolt they would screw together; but with the square thread, if the pitch is slightly altered, no difference of diameter would allow the nut to fit.

With the development of thread grinding machines the difficulty formerly associated with the hardening of a cut thread tap no longer exists. This is because the thread can be accurately ground to size and shape after the blank has been correctly heat treated.

Hand Chasers

Comb chasers for use by hand are made in pairs for

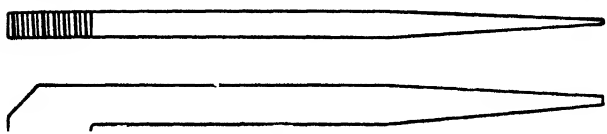


FIG. 286.—Inside Chaser.

internal and external work. Fig. 286 shows the inside chasers, and Fig. 287 the outside.

The teeth are the exact formation or counterpart of the screw thread they are to cut. The teeth of chasers are

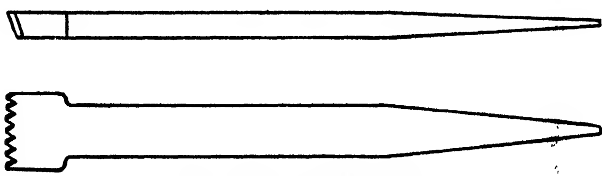


FIG. 287.—Outside Chaser.

formed by means of a hob, which is in itself a large duplicate of the screw.

Hand chasers are chiefly used for cutting small threads in brass, or for rounding off the tops and bottoms of threads that have been previously cut in the screw-cutting lathe. The ability to cut a thread on the solid metal by

means of the chaser depends to a great extent on the dexterity of the workman.

In using the chaser a rest must be placed in the tool holder at such a height as to bring the cutting edge of the chaser radial with the axis of the work. The handle of the chaser must be grasped firmly by the right hand, with the knuckles below, the left hand being round the head of the tool holder, with the thumb free to hold the end of the chaser. To obtain the thread, press firmly against the work, and at the same time, by a uniform movement, keep the chaser moving precisely the distance of one thread from the next. The cut can be regulated when making a start by pressure of the thumb on the end of the chaser. Care must be taken to keep the cutting edge of the tool parallel with the work, otherwise the thread will not be uniform in pitch.

Vee-shaped threads that have been cut by means of a vee tool in the screw-cutting lathe are frequently brought to their exact size by means of the chaser.

The Whitworth thread requires to be rounded top and bottom, and while it is possible to round the point of the tool, it is not possible to round the top of the thread by the same means. Therefore the chaser will give a more perfect shaped thread than can be obtained by means of the screw-cutting tool alone.

Change Wheels

For the purpose of cutting threads in the screw-cutting lathe, change wheels are provided. A full set generally consists of twenty-two wheels, rising from 20 to 100 by fives, and from 100 to 120 by tens, and containing two wheels of equal size, usually with 50 or 60 teeth which can be used when cutting a thread of the same pitch as the leading screw, and thereby doing away with the necessity of using a compound train.

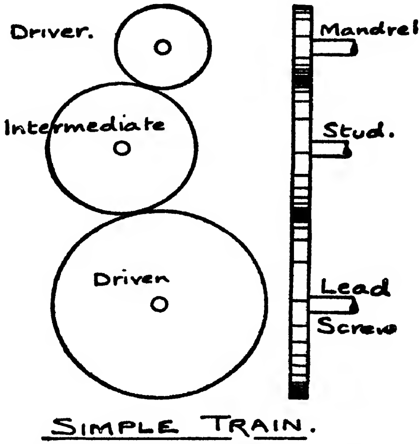


FIG. 288.—Simple Train of Wheels.

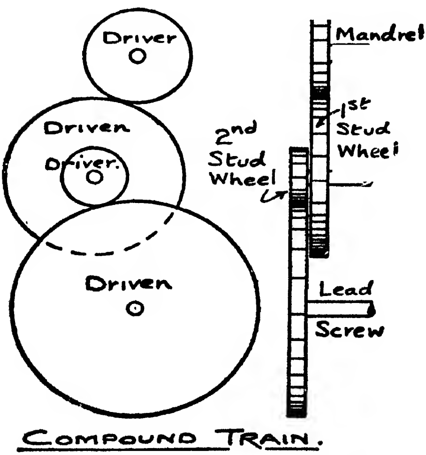


FIG. 289.—Compound Train of Wheels.

To calculate the wheels required for cutting a certain pitch screw, it is necessary to know how the ratio is obtained,

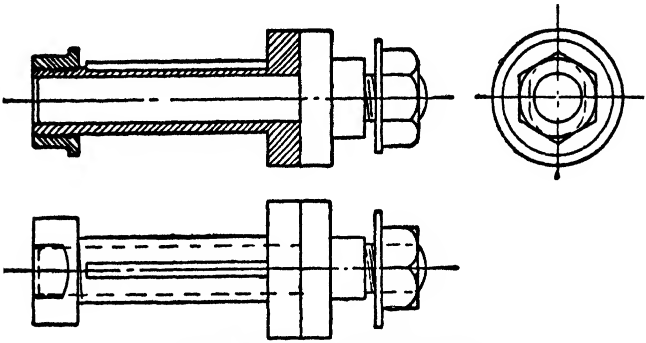


FIG. 290.—Stud for Change Wheels.

and exactly where the driving and driven wheels are to be placed.

Figs. 288 and 289 illustrate very clearly where the

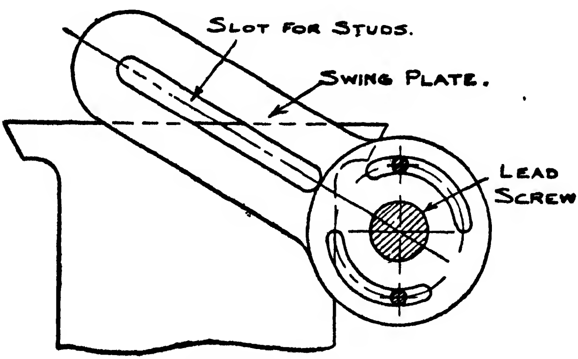


FIG. 291.—Swing Plate.

driving and driven wheels are placed. The first driving or mandrel wheel fits either directly on the lathe mandrel, or else on a small shaft from which it can be engaged with a wheel on the mandrel through the medium of a tumbler gear.

The intermediate wheel fits on a movable stud as illustrated, Fig. 290, which can be secured in the desired position in the slot of a swing frame attached to the leading screw, Fig. 291.

The lead screw wheel fits directly on to the leading screw.

All wheels are fitted with keyways, the shafts having feathers of suitable size.

Ratio

The fundamental principle of screw-cutting being the ratio of the lead screw and the screw to be cut, before the change wheels can be found it is necessary to first find the ratio. In most cases it is a very simple matter, but when odd pitch screws have to be cut it is sometimes puzzling to the novice.

To find the ratio of driving and driven wheels the following always holds good :—As the number of threads per inch of the lead screw is to the number of threads per inch of the screw to be cut, so is the number of teeth in the mandrel wheel or driver to the number of teeth in the lead screw wheel as driven.

In a fractional form this would be—

$$\frac{\text{No. of threads per inch of leading screw}}{\text{No. of threads per inch of screw to be cut}} = \frac{\text{Wheel on mandrel}}{\text{Wheel on lead screw}}.$$

It will be seen from the above that whatever the pitch of the lead screw, if it is required to cut a screw of similar pitch, the ratio would be as 1 is to 1, and therefore any two wheels of equal number of teeth would do, with any wheel to gear up as shown in Fig. 292.

If twice the number of threads per inch or half the

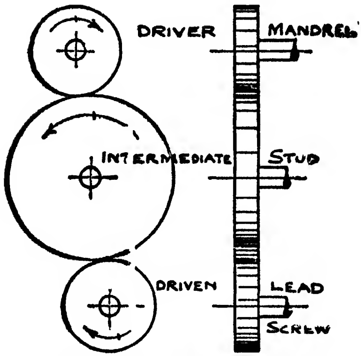


FIG. 292.—Change Wheels.

pitch of the lead screw is to be cut, then the driving or mandrel wheel would be half the size of the lead screw wheel, as shown in Fig. 293, or a ratio of 1 to 2.

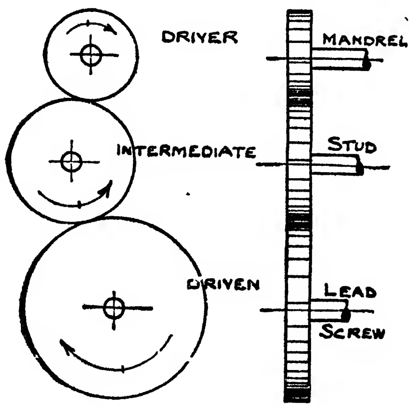


FIG. 293.—Change Wheels.

Should twice the pitch of the lead screw be required, then the driver or mandrel wheel would have to be twice the size of the driven wheel, as illustrated in Fig. 294, or a ratio of 2 to 1.

When working out change wheels remember:—If the pitch of the thread to be cut is greater than the pitch of the lead screw, then the driver or drivers multiplied together must be greater than the driving or driven

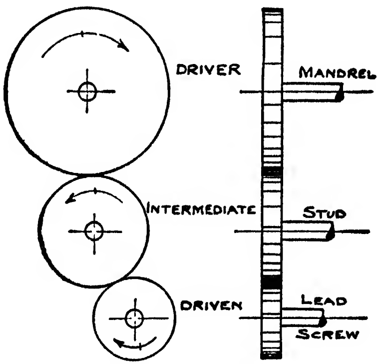


FIG. 294.—Change Wheels.

multiplied together. In other words, if a finer thread is to be cut than on the lead, the work must revolve faster than the lead screw.

Examples of Change Wheels

Example 1.—It is required to cut a screw having $\frac{1}{4}$ in. pitch on a lathe with a lead screw of $\frac{1}{4}$ in. pitch. Then—

$$\frac{\frac{1}{4}\text{ in. pitch or four threads per inch}}{\frac{1}{4}\text{ in. pitch or four threads per inch}} = \frac{\text{driver}}{\text{driven}} = \frac{4}{4}.$$

In this example, and in any similar case in which the ratio is equal, or, in other words, when a screw is required having the same pitch as the lead, any two wheels having the same number of teeth will answer the purpose; one being placed on the lathe mandrel, the other on the lead screw, with any wheel to gear up.

Example 2.—It is required to cut a screw having $\frac{1}{4}$ in. pitch, or four threads per inch, on a lathe having a lead screw of $\frac{1}{2}$ in. pitch. Then—

$$\frac{\frac{1}{2}\text{ in. pitch or two threads per inch}}{\frac{1}{4}\text{ in. pitch or four threads per inch}} = \frac{\text{driver}}{\text{driven}} = \frac{2}{4},$$

or a ratio of 1 to 2, therefore any wheels of that ratio could be used. By multiplying both numbers by 20 we get 20 and 40, multiplying by 30 we get 30 and 60, multiplying by 40 we get 40 and 80. Therefore any of these numbers can be used, the smallest being the driver, and being placed on the lathe mandrel.

Example 3.—It is required to cut a screw having $\frac{1}{20}$ in. pitch, or twenty threads per inch, on a lathe having a lead screw of $\frac{1}{4}$ in. pitch or four threads per inch. Then—

$$\frac{\frac{1}{4}\text{ in. pitch or four threads per inch}}{\frac{1}{20}\text{ in. pitch or twenty threads per inch}} = \frac{\text{driver}}{\text{driven}} = \frac{4}{20},$$

or a ratio of 1 to 5, therefore any wheels having teeth in that ratio can be used. Multiplying by 20 we get 20 and 100; therefore 20 driver, 100 driven.

Example 4.—It is required to cut a screw having 1 in. pitch on a lathe having a lead screw of $\frac{1}{4}$ in. pitch. Then—

$$\frac{\frac{1}{4}\text{ in. pitch or four threads per inch}}{1\text{ in. pitch or one thread per inch}} = \frac{\text{driver}}{\text{driven}} = \frac{4}{1},$$

or a ratio of 4 to 1. Multiplying by 20 we get 80 and 20, multiplying by 25 we get 100 and 25, multiplying by 30 we get 120 and 30. Therefore any of these pairs can be used, the largest wheel driving.

Fractional Pitches

When calculating change wheels for fractional pitches, it is best to work on the universal rule for finding ratio, which is:—

Find the distance in inches which contain the minimum number of complete threads in the screw to be cut, and also the number of threads in a similar distance on the lead screw. The result will be the ratio that is required between the driver and the driven wheels. To take an example, if a screw having a pitch of $2\frac{7}{8}$ in. is to be cut on a lathe having $\frac{1}{4}$ in. pitch lead screw, find the ratio.

A screw having a pitch of $2\frac{7}{8}$ in. would have eight complete threads in 23 inches; on the same distance of the lead screw there would be ninety-two complete threads. Therefore the ratio would be as 92 is to 8, or as 23 is to 2.

To take another example. If a screw having $1\frac{7}{8}$ threads per inch is to be cut on a lathe having a lead screw of four threads per inch, find the ratio. A screw having $1\frac{7}{8}$ threads per inch would have fifteen complete threads in 8 inches; on the same distance of the lead screw there would be thirty-two complete threads. Therefore, the ratio would be as 32 is to 15.

Example 5.—It is required to cut a screw having $9\frac{1}{2}$ threads to the inch on a lathe having $\frac{1}{4}$ in. pitch lead screw. Then—

$$\frac{\frac{1}{4}\text{ in. pitch or eight threads in 2 in.}}{\frac{1}{9\frac{1}{2}}\text{ in. pitch or nineteen threads in 2 in.}}=\frac{\text{driver}}{\text{driven}}=\frac{8}{19},$$

or a ratio of 8 to 19. Multiplying by 5 we get 40 and 95. Therefore, 40 driver, 95 driven.

Example 6.—It is required to cut a screw having $1\frac{1}{4}$ in. pitch on a lathe having a lead screw of $\frac{1}{4}$ in. pitch. Then—

$$\frac{\frac{1}{4}\text{ in. pitch or twenty threads in 5 in.}}{1\frac{1}{4}\text{ in. pitch or four threads in 5 in.}}=\frac{\text{driver}}{\text{driven}}=\frac{20}{4},$$

or a ratio of 5 to 1. Multiplying by 20 we get 100 and 20. Therefore, 100 driver or mandrel wheel, 20 driven or lead screw wheel.

Example 7.—It is required to cut a screw having $3\frac{1}{2}$ threads per inch on a lathe having a lead screw of $\frac{1}{2}$ in. pitch. Then—

$$\frac{\frac{1}{2}\text{ in. pitch or four threads in 2 in.}}{\frac{1}{3\frac{1}{2}}\text{ in. pitch or seven threads in 2 in.}}=\frac{\text{driver}}{\text{driven}}=\frac{4}{7}$$

The ratio being as 4 is to 7, multiplying by 5 we get 20 and 35. Therefore, 20 driver or mandrel wheel, 35 driven or lead screw wheel.

Examples of Compound Gear

As it is not always possible to obtain the required ratio by means of a simple train of wheels, a compound train must be used, Fig. 289.

To take an example. It is required to cut a screw having two threads per inch on a lathe having a lead screw of two threads per inch, when the lathe is not supplied with two wheels of the same size.

In this case the ratio is equal, and any two wheels of the same size could be used. As the lathe is not supplied with two wheels of the same size a compound train must be used. This can be obtained by having two 2 to 1 gears. Thus—

$$\frac{2}{1}\times\frac{1}{2},$$

and then multiplying by any suitable number. Multiplying by 20 and 50 we get—

$$\frac{40}{20}\times\frac{50}{100}.$$

Therefore, 40 and 50 drivers, 20 and 100 driven.

Example 8.—It is required to cut a screw having twenty-five threads per inch on a lathe having a lead screw of four threads per inch. Then—

$$\frac{\frac{1}{4}\text{ in. pitch or four threads per inch}}{\frac{1}{25}\text{ in. pitch or twenty-five threads per inch}}=\frac{\text{driver}}{\text{driven}}=\frac{4}{25}.$$

Multiplying $4 \times 5 = 20$, this being the smallest wheel in the set, it cannot be reduced, and multiplying $25 \times 5 = 125$, which in many cases is too large by 5; that being so, a compound train must be used.

To obtain the wheels put down the ratio, and multiply both figures by any suitable number, in this case by 10 and 100, thus—

$$\frac{40}{250} \times \frac{100}{100},$$

and then cancel to obtain suitable wheels, by dividing by 5, thus—

$$\frac{40}{\underset{50}{\cancel{250}}} \times \frac{\overset{20}{\cancel{100}}}{100}.$$

Then 40 and 20 drivers, 50 and 100 driven.

Example 9.—It is required to cut a screw having forty-five threads per inch on a lathe having a lead screw of four threads per inch. Then—

$$\frac{\frac{1}{4}\text{ in. pitch or four threads per inch}}{\frac{1}{45}\text{ in. pitch or forty-five threads per inch}}=\frac{\text{driver}}{\text{driven}}=\frac{4}{45}.$$

Multiplying by 10 and 100, and dividing by 5, thus—

$$\frac{40}{\underset{90}{\cancel{450}}} \times \frac{\overset{20}{\cancel{100}}}{100}=\frac{40}{90} \times \frac{20}{100}.$$

Then 40 and 20 drivers, 90 and 100 driven.

Change Wheels for Multiple Threads

In order to cut multiple threads, it is usual to choose a first driving wheel that can be divided equally by the number of different threads or starts in the screw to be cut. For example, to cut a double-threaded screw, any first driver would be used that had an even number of teeth; to cut a triple, any first driver would do that would divide equally by 3, such as 30, 60, or 90 would do.

Example 10.—A compound thread having a lead of $1\frac{1}{2}$ in. is to be cut on a lathe having a lead screw of $\frac{1}{4}$ in. pitch. Then—

$$\frac{\frac{1}{4}\text{ in. pitch or twelve threads in 3 in.}}{1\frac{1}{2}\text{ in. lead or two threads in 3 in.}} = \frac{12}{2}.$$

The ratio is 6 to 1. Multiplying by 20 we get 120 and 20, and as 120 will divide equally by 2, it would be a suitable gear.

Example 11.—A five-start thread having a lead of $2\frac{1}{2}$ in. is required to be cut on a lathe having a lead screw of two threads per inch. Then—

$$\frac{\frac{1}{2}\text{ in. pitch or ten threads in 5 in.}}{2\frac{1}{2}\text{ in. lead or two threads in 5 in.}} = \frac{10}{2}.$$

The ratio being as 5 is to 1. Multiplying by 20 we get 100 and 20, and as 100 can be divided equally by 5, it would be a suitable gear.

Prime Numbers

In finding the ratio for cutting certain pitch screws, it will sometimes occur that none of the change wheels in the set contain the required number of teeth. This is owing to the fact that prime numbers are required.

To take an example. It is required to cut a screw

having thirty-one threads per inch on a lathe having a lead screw of two threads per inch.

The ratio is as 2 is to 31. Multiplying by 10 and 80, and dividing by 2, we get

$$\frac{20}{\overset{}{\cancel{310}}_{155}} \times \frac{\overset{40}{\cancel{80}}}{80} = \frac{20}{155} \times \frac{40}{80}.$$

155 being the lowest figure to which we can bring the 31, it would require a special wheel to cut the thread required.

The following is a list of prime numbers between 23 and 100:—29, 31, 37, 41, 43, 47, 53, 59, 61, 67, 71, 73, 79, 83, 89, and 97, and with these no time should be wasted in attempting to factorise.

Approximations for Fractional Threads

When it is required to cut a thread, the ratio of which cannot be factorised, two methods can be adopted. By one a special wheel can be cut, and by the other the terms of the ratio can be altered slightly, and by that means an approximation can be obtained.

If accuracy is necessary, and it often is with fractional pitches, then a special wheel must be cut; if a slight inaccuracy can be allowed, then the following method can be followed:—

Example.—It is required to cut a thread having 67.7 threads in 12 in. on a lathe having a lead screw of $\frac{1}{2}$ in. pitch. Then—

$$\frac{\frac{1}{2}\text{ in. pitch or 24 threads in 12 in.}}{\frac{12}{67\cdot 7}\text{ in. pitch or } 67\cdot 7 \text{ threads in 12 in.}} = \frac{24}{67\cdot 7} = \frac{240}{677},$$

or a ratio of 240 to 677.

As 677 will not factorise, by adding 3 we get a ratio of 240 to 680. This can be expressed as

$$\frac{12 \times 20}{17 \times 40}.$$

Multiplying the 12 and 17 by 5 we get

$$\frac{60 \times 20}{85 \times 40}.$$

Then 60 and 20 drivers, 85 and 40 driven.

Metric Pitches

Cutting threads approximately to metric pitches on an ordinary lathe is very simple. The metre is 39.37 in., or about $\frac{1}{200}$ of an inch less than $39\frac{3}{8}$ in., and this difference can be neglected.

As there are 1,000 mm. in the metre (or $39\frac{3}{8}$ in.), there are 8,000 mm. in $39\frac{3}{8} \times 8 = 315$ in., and assuming a lead screw of $\frac{1}{2}$ in. pitch, this would be equivalent to $315 \times 2 = 630$ threads in 8,000 mm.

Example.—If a screw of 1 mm. pitch was required, the ratio between the required screw and the leading screw would be

$$630 : 8000 :: 63 : 800.$$

As 1 mm. is less than the pitch of the leading screw, the smaller wheel drives the greater.

Thus, for working out the change wheels for any screw of millimetre pitch, this fraction is a constant number, and a special wheel having 63 teeth, termed a translating wheel, must be used. For more accurate results a translating wheel having 127 teeth may be used.

To find the change wheels, multiply the constant by the pitch of the screw required.

Example.—Find the change wheels to cut a thread of 5 mm. pitch. Then—

$$\frac{63}{800} \times 5 = \frac{63}{80} \times \frac{5}{10}.$$

By adding ciphers to the numbers 5 and 10 we get

$$\frac{63 \times 50}{80 \times 100}.$$

Therefore 63 and 50 drivers, 80 and 100 driven.

Table of Change Wheels for Cutting Various Threads

Lead Screw ½ in. Pitch

Threads to be cut per Inch.	Drivers.	Driven.	Threads to be cut per Inch.	Drivers.	Driven.
1	80	40	7½	20	75
1⅛	80	45	8	20	80
1¼	80	50	9	20	90
1⅜	80	55	10	20	100
1½	80	60	11	20	110
1⅝	60 100	75 65	12	20	120
1¾	80	70	13	20 50	65 100
1⅞	80	75	14	20 75	100 105
2	60	60	15	20 80	100 120
2¼	40	45	16	25 30	50 120
2⅜	80	95	17	20 60	85 120
2½	40	50	18	25 40	75 120
2⅝	80	105	19	25 40	95 100
2¾	40	55	20	20 40	80 100
2⅞	40 100	115 25	21	20 40	70 120
3	40	60	22	20 30	60 110
3¼	40	65	23	20 50	100 115
3½	40	70	24	25 30	75 120
4	30	60	25	20 30	75 100
4½	40	90	26	20 25	65 100
5	30	75	28	20 25	70 100
5½	20	55	30	24 40	100 120
6	30	90	35	20 30	100 105
6½	20	65	40	20 30	100 120
7	20	70	50	20 20	100 100

CHANGE WHEELS FOR CUTTING MILLIMETRE PITCH

Lead Screw $\frac{1}{2}$ in. Pitch

Threads to be cut in Millimetres.	Drivers.	Driven.	Threads to be cut in Millimetres.	Drivers.	Driven.
1	36 35	160 100	6	63 60	100 80
2	63 20	100 80	7	63 70	100 80
3	63 30	100 80	8	63 80	100 80
4	63 40	100 80	9	63 90	100 80
5	63 50	100 80	10	63 100	100 80

TABLE OF CHANGE WHEELS FOR CUTTING VARIOUS PITCH THREADS

Lathe Lead Screw $\frac{1}{4}$ in. Pitch

Threads to be cut per Inch.	Drivers.	Driven.	Threads to be cut per Inch.	Drivers.	Driven.
1	100	25	$7\frac{1}{2}$	40	75
$1\frac{1}{8}$	60 80	45 30	8	40	80
$1\frac{1}{4}$	80	25	9	40	90
$1\frac{3}{8}$	80 120	110 30	10	40	100
$1\frac{1}{2}$	80	30	11	40	110
$1\frac{5}{8}$	60 80	65 30	12	40	120
$1\frac{3}{4}$	80	35	13	20	65
$1\frac{7}{8}$	40 80	50 30	14	20	70
$2\frac{1}{4}$	40 100	75 30	15	20	75
$2\frac{3}{8}$	40 100	95 25	16	20	80
$2\frac{1}{2}$	80	50	17	20	85
$2\frac{5}{8}$	40 100	105 25	18	20	90
$2\frac{3}{4}$	80	55	19	20	95
$2\frac{7}{8}$	40 100	115 25	20	20	100
3	80	60	21	20 40	60 70
$3\frac{1}{4}$	80	65	22	20	110
$3\frac{1}{2}$	40	35	23	20	115
4	40	40	24	20	120
$4\frac{1}{4}$	40	45	25	30 40	75 100
5	40	50	26	20 30	60 65
$5\frac{1}{2}$	40	55	28	20 30	40 105
6	30	45	30	20 60	90 100
$6\frac{1}{2}$	40	65	40	20 55	100 110
7	40	70	50	20 30	75 100

To Prove a Train of Wheels

If the train of wheels is a simple one, divide the number of teeth in the driven or lead screw wheel by the number of teeth in the mandrel wheel or driver, and multiply by the number of threads per inch in the lead screw.

To take an example. A train of wheels has 40 teeth in the driving wheel, and 20 in the driven, the lead screw of the lathe having four threads per inch. Find the number of threads being cut. Then—

$$20 \div 40 = 0{\cdot}5.$$

$0{\cdot}5 \times 4 = 2$, or two threads per inch.

In a compound train multiply the driving wheels together and the driven wheels together, and divide the product of the driven by the product of the drivers. The quotient multiplied by the number of threads per inch on the lead screw will give the number of threads being cut.

Example.—A compound train of wheels having 40 and 50 drivers, with 125 and 100 driven, with a lead screw of four threads per inch. Find the thread being cut. Then—

$$\frac{125 \times 100}{40 \times 50} = \frac{25}{4} = 6{\cdot}25.$$

$$6{\cdot}25 \times 4 = 25.$$

Or the lathe will be set to cut twenty-five threads per inch.

British Standard Fine Screw Thread

(Recommended by the British Standards Institute as a standard for screws subjected to shock and vibration, or where extra strength of core is required.)

Full Diameter in Inches.	Number of Threads per Inch.	Pitch in Inches.	Full Diameter in Inches.	Number of Threads per Inch.	Pitch in Inches.
$\frac{1}{4}$ (0·25)	26	0·0385	*$2\frac{7}{8}$ (2·875)	6	0·1667
$\frac{5}{16}$ (0·3125)	22	0·0455	3	5	0·2000
$\frac{3}{8}$ (0 375)	20	0·0500	*$3\frac{1}{8}$ (3·125)	5	0·2000
$\frac{7}{16}$ (0·4375)	18	0·0556	$3\frac{1}{4}$ (3·25)	5	0·2000
$\frac{1}{2}$ (0·5)	16	0·0625	$3\frac{3}{8}$ (3·375)	5	0·2000
$\frac{9}{16}$ (0·5625)	16	0·0625	$3\frac{1}{2}$ (3·5)	4·5	0·2222
$\frac{5}{8}$ (0·625)	14	0·0714	*$3\frac{5}{8}$ (3·625)	4·5	0·2222
$\frac{11}{16}$ (0·6875)	14	0·0714	$3\frac{3}{4}$ (3·75)	4·5	0·2222
$\frac{3}{4}$ (0·75)	12	0·0833	*$3\frac{7}{8}$ (3·875)	4·5	0·2222
$\frac{13}{16}$ (0·8125)	12	0·0833	4	4·5	0·2222
$\frac{7}{8}$ (0·875)	11	0·0909	*$4\frac{1}{8}$ (3·125)	4·5	0·2222
*$\frac{15}{16}$ (0·9375)	11	0·0909	*$4\frac{1}{4}$ (4·25)	4	0·2500
1	10	0·1000	$4\frac{3}{8}$ (4·375)	4	0·2500
$1\frac{1}{8}$ (1·125)	9	0·1111	$4\frac{1}{2}$ (4·5)	4	0·2500
$1\frac{1}{4}$ (1·25)	9	0·1111	*$4\frac{5}{8}$ (4·625)	4	0·2500
$1\frac{3}{8}$ (1·375)	8	0·1250	*$4\frac{3}{4}$ (4·75)	4	0·2500
$1\frac{1}{2}$ (1·5)	8	0·1250	*$4\frac{7}{8}$ (4·875)	4	0·2500
$1\frac{5}{8}$ (1·625)	8	0·1250	5	4	0·2500
$1\frac{3}{4}$ (1·75)	7	0·1429	*$5\frac{1}{8}$ (5·125)	4	0·2500
*$1\frac{7}{8}$ (1·875)	7	0·1429	*$5\frac{1}{4}$ (5·25)	3·5	0·2857
2	7	0·1429	*$5\frac{3}{8}$ (5·375)	3·5	0·2857
$2\frac{1}{8}$ (2·125)	7	0·1429	$5\frac{1}{2}$ (5·5)	3·5	0·2857
$2\frac{1}{4}$ (2·25)	6	0·1667	*$5\frac{5}{8}$ (5·625)	3·5	0·2857
*$2\frac{3}{8}$ (2·375)	6	0·1667	*$5\frac{3}{4}$ (5·75)	3·5	0·2857
$2\frac{1}{2}$ (2·5)	6	0·1667	*$5\frac{7}{8}$ (5·875)	3·5	0·2857
*$2\frac{5}{8}$ (2·625)	6	0·1667	6	3·5	0·2857
$2\frac{3}{4}$ (2·75)	6	0·1667			

* The Committee recommend that for general use these sizes be dispensed with.

Whitworth Gas Threads

Size.	Diameter at Top of Thread.	Diameter at Bottom of Thread.	Number of Threads per Inch.	Size.	Diameter at Top of Thread.	Diameter at Bottom of Thread.	Number of Threads per Inch.
Inch.	Inch.	Inch.		Inch.	Inch.	Inch.	
$\frac{1}{8}$	0·3825	0·3367	28	$1\frac{5}{8}$	2·021	1·905	11
$\frac{1}{4}$	0·518	0·4506	19	$1\frac{3}{4}$	2·047	1·9305	11
$\frac{3}{8}$	0·6563	0·5889	19	$1\frac{7}{8}$	2·245	2·1285	11
$\frac{1}{2}$	0·8257	0·7342	14	2	2·347	2·2305	11
$\frac{5}{8}$	0·9022	0·8107	14	$2\frac{1}{4}$	2·5875	2·471	11
$\frac{3}{4}$	1·041	0·9495	14	$2\frac{1}{2}$	3·0013	2·8848	11
$\frac{7}{8}$	1·189	1·0975	14	$2\frac{3}{4}$	3·247	3·1305	11
1	1·309	1·1925	11	3	3·485	3·3685	11
$1\frac{1}{8}$	1·492	1·3755	11	$3\frac{1}{4}$	3·6985	3·582	11
$1\frac{1}{4}$	1·65	1·5335	11	$3\frac{1}{2}$	3·912	3·7955	11
$1\frac{3}{8}$	1·745	1·6285	11	$3\frac{3}{4}$	4·1255	4·009	11
$1\frac{1}{2}$	1·8825	1·765	11	4	4·339	4·223	11

Approximate Sizes of Gas Threads in Inches

Size.	Diameter at Top of Thread.	Diameter at Bottom of Thread.	Number of Threads per Inch.	Size.	Diameter at Top of Thread.	Diameter at Bottom of Thread.	Number of Threads per Inch.
Inch.	Inch.	Inch.		Inch.	Inch.	Inch.	
$\frac{1}{8}$	$\frac{3}{8}$	$\frac{5}{16}+\frac{1\cdot5}{64}$	28	$1\frac{5}{8}$	$2\frac{1}{64}$	$1\frac{7}{8}+\frac{1}{32}$	11
$\frac{1}{4}$	$\frac{1}{2}+\frac{1}{64}$	$\frac{7}{16}+\frac{1}{64}$	19	$1\frac{3}{4}$	$2\frac{3}{64}$	$1\frac{15}{16}$	11
$\frac{3}{8}$	$\frac{5}{8}+\frac{1}{32}$	$\frac{1}{2}+\frac{3}{32}$	19	$1\frac{7}{8}$	$2\frac{1}{4}$	$2\frac{1}{8}$	11
$\frac{1}{2}$	$\frac{13}{16}+\frac{1}{64}$	$\frac{11}{16}+\frac{3}{64}$	14	2	$2\frac{5}{16}+\frac{1}{32}$	$2\frac{3}{16}+\frac{3}{64}$	11
$\frac{5}{8}$	$\frac{7}{8}+\frac{1}{32}$	$\frac{13}{16}$	14	$2\frac{1}{4}$	$2\frac{9}{16}+\frac{1}{32}$	$2\frac{7}{16}+\frac{1}{32}$	11
$\frac{3}{4}$	$1\frac{1}{32}$	$\frac{15}{16}$	14	$2\frac{1}{2}$	3	$2\frac{7}{8}$	11
$\frac{7}{8}$	$1\frac{1}{16}$	$1\frac{3}{32}$	14	$2\frac{3}{4}$	$3\frac{1}{4}$	$3\frac{1}{8}$	11
1	$1\frac{5}{16}$	$1\frac{3}{16}$	11	3	$3\frac{7}{16}+\frac{3}{64}$	$3\frac{5}{16}+\frac{3\cdot5}{64}$	11
$1\frac{1}{8}$	$1\frac{7}{16}+\frac{3\cdot5}{64}$	$1\frac{3}{8}$	11	$3\frac{1}{4}$	$3\frac{11}{16}+\frac{1}{64}$	$3\frac{9}{16}+\frac{1}{64}$	11
$1\frac{1}{4}$	$1\frac{5}{8}+\frac{1}{32}$	$1\frac{1}{2}+\frac{1}{32}$	11	$3\frac{1}{2}$	$3\frac{7}{8}+\frac{1}{32}$	$3\frac{3}{4}+\frac{3}{64}$	11
$1\frac{3}{8}$	$1\frac{3}{4}$	$1\frac{5}{8}$	11	$3\frac{3}{4}$	$4\frac{1}{8}$	4	11
$1\frac{1}{2}$	$1\frac{7}{8}$	$1\frac{3}{4}+\frac{1}{64}$	11	4	$\frac{5}{16}+\frac{1}{32}$	$4\frac{3}{16}+\frac{1}{32}$	11

British Association Screw Threads

Schedule of Sizes

Designating Number.	Full Diameter.	Approximate Full Diameter in Inches.	Pitch.	Effective Diameter.	Core Diameter.
	Mm.		Mm.	Mm.	Mm.
0	6·0	0·236	1·0	5·4	4·8
1	5·3	0·209	0·9	4·76	4·22
2	4·7	0·185	0·81	4·215	3·73
3	4·1	0·161	0·73	3·66	3·22
4	3·6	0·142	0 66	3·205	2·81
5	3·2	0·126	0·59	2·845	2·49
6	2·8	0·110	0·53	2·48	2·16
7	2·5	0·098	0·48	2·21	1·92
8	2·2	0·087	0·43	1·94	1·68
9	1·9	0·075	0·39	1·665	1·43
10	1·7	0·067	0·35	1·49	1·28
11	1·5	0·059	0·31	1·315	1·13
12	1·3	0·051	0·28	1·13	0·96
13	1·2	0·047	0·25	1·05	0·9
14	1·0	0·039	0·23	0·86	0·72
15	0·9	0·035	0·21	0·775	0·65
16	0·79	0·031	0·19	0·675	0·56
17	0·70	0·028	0·17	0·6	0·50
18	0·62	0·024	0·15	0·53	0·44
19	0·54	0·021	0·14	0·455	0·37
20	0·48	0·019	0·12	0·41	0·34
21	0·42	0·017	0·11	0·355	0·29
22	0·37	0·015	0·10	0·31	0·25
23	0·33	0·013	0·09	0·275	0·22
24	0·29	0·011	0·08	0·24	0·19
25	0·25	0·010	0·07	0·21	0·17

The figures in column 3 are given for convenience only, and should, in no case, be worked to where satisfactory interchangeability is required.

Whitworth's Standard Taps

Outside Diameter.	Full Length.	Length of Screw Part.	Length of Square.	Size of Square.	Diameter at Bottom of Thread.	Threads per Inch.
1/16	1 1/2	5/8	3/16	...	0·0413	60
3/32	1 5/8	3/4	3/16	...	0·0671	48
1/8	1 3/4	7/8	1/4	...	0·093	40
5/32	1 7/8	7/8	1/4	...	0·112	32
3/16	2	1	5/16	...	0·134	24
7/32	2 1/8	1 1/16	5/16	...	0·165	24
1/4	2 1/4	1 1/8	3/8	...	0·186	20
5/16	2 1/2	1 3/8	7/16	5/32	0·241	18
3/8	2 3/4	1 1/2	1/2	7/32	0·295	16
7/16	3 1/4	1 3/4	1/2	9/32	0·346	14
1/2	3 1/2	2	9/16	5/16	0·393	12
9/16	3 3/4	2 1/8	9/16	5/16	0·455	12
5/8	4	2 1/4	5/8	3/8	0·508	11
11/16	4 1/4	2 3/8	11/16	3/8	0·571	11
3/4	4 1/2	2 1/2	3/4	7/16	0·622	10
13/16	4 3/4	2 5/8	3/4	7/16	0·684	10
7/8	5	2 7/8	13/16	1/2	0·732	9
15/16	5 1/4	3	13/16	1/2	0·795	9
1	5 1/2	3 1/4	7/8	5/8	0·84	8
1 1/8	6	3 1/2	1	11/16	0·942	7
1 1/4	6 1/2	3 3/4	1 1/8	13/16	1·067	7
1 3/8	7 1/2	4 1/4	1 1/8	13/16	1·161	6
1 1/2	8	4 3/4	1 1/4	1	1·286	6
1 5/8	8 1/2	5 1/4	1 1/4	1	1·368	5
1 3/4	9	5 1/2	1 3/8	1 1/8	1·494	5
1 7/8	9 1/2	5 3/4	1 3/8	1 1/8	1·59	4 1/2
2	10	6	1 1/2	1 5/16	1·715	4 1/2
2 1/8	10 1/2	6 1/4	1 1/2	1 3/8	1·84	4 1/2
2 1/4	11	6 3/4	1 5/8	1 1/2	1·93	4
2 3/8	11 1/2	7 1/4	1 5/8	1 5/8	2·054	4
2 1/2	12	7 3/4	1 3/4	1 5/8	2·18	4
2 5/8	12 1/2	8 1/4	1 3/4	1 3/4	2·304	4
2 3/4	13	8 3/4	1 7/8	1 3/4	2·384	3 1/2
2 7/8	13 1/2	9 3/4	1 7/8	1 7/8	2·509	3 1/2
3	14	10 3/4	2	2	2·634	3 1/2

Cutting Multiple Threads

The cutting of multiple threads forms an important part of the turner's work. Theoretically, the cutting of these threads is a very simple matter, the calculations and marking being easy, but in practice a considerable amount of experience is necessary before a perfect double, triple, or quadruple thread can be cut.

The usual method adopted for cutting multiple threads is to work out the necessary change wheels to give the required lead, arranging to have a first driver that can be divided into an equal number of parts corresponding with the number of separate threads or starts on the screw to be cut.

The method of procedure is then as follows: One thread is cut nearly to depth, within, say, about three-thousandths of an inch of finished size. The lathe is then brought to the starting position; the first driver is divided into the number of parts corresponding with the number of separate threads. The intermediate or first driven wheel is marked on the two teeth coming on each side of a mark on the first driver. The swing plate is then lowered and the lathe pulled round until the next mark on the driver gears with the two marks on the driven wheel. The next thread is then cut, the operation being repeated until all the threads are cut. It is usual to take a finishing cut for depth down each space, keeping the tool exactly the same depth for each cut.

In cutting multiple threads of such a pitch as to require the marking of the lathe, then the mark on the lathe mandrel must either be altered for each cut, or else numbered 1, 2, 3, etc.

A square thread is not required to fit tightly and accurately all over; it is better practice to cut the grooves slightly deeper than the theoretical depth by about

two thousandths, and then rely upon the sides to take up all movement and wear.

In cutting coarse pitch threads when the thread angle is greater than 45°, it is unusual to cut them in the ordinary lathe, as the strain is too great for the change wheels. When they are necessary they should be milled or cut by special machine. In some cases, however, a special arrangement can be attached to the ordinary screw-cutting lathe, by means of which the leading screw itself is driven from the countershaft, and the spindle driven by means of the lead screw.

Cutting Odd Pitch Threads

In cutting certain pitch threads in lathes having lead screws of any pitch, the question of cross threading arises.

If a thread could be cut in one traverse of the tool, no difficulty would ever arise from cross threading, but as most threads require several cuts to complete the screw, it is necessary to know when there is the possibility of not correctly picking up the thread.

When cutting a single-threaded screw having an even number of threads per inch, on a lathe having two threads per inch, the nut can be dropped in at any position without fear of splitting the thread, that is, if the tool is not moved longitudinally after the first cut.

If a screw with an even number of threads per inch is to be cut in a lathe having a lead screw of four threads per inch, then all threads that are multiple of four can be cut without fear of cross threading; these would be 4, 8, 12, 16, 24, etc.

When cutting screws having an odd number of threads per inch, in lathes fitted with lead screws having an even number of threads per inch, it is always

necessary to mark the lathe in order to correctly start the cut.

In cutting fractional threads, such as 1⅛ thread per in. or 1⅛ in. pitch, it is necessary in all cases to mark the lathe whatever the pitch of the lead screw.

In cutting multiple threads the question of correctly picking up the cut can be determined by taking each cut separately. Thus a ½-in. pitch screw of 1 in., 1½ in., or 2 in. lead to be cut on a lathe having a ½-in. pitch lead screw, would be done in the same manner as a single thread of 1 in., 1½ in., or 2 in. pitch, and marking up would be required. The same would apply when cutting a ¼-in. pitch screw of ½ in., 1 in., or 1½ in. lead on a lathe having a lead screw of four threads per inch.

Cutting Multiple Threads

In cutting double or triple threads on a lathe having a ½-in. pitch lead screw, if the pitch of the former is an aliquot part of the pitch of the lead screw, the driving plate can be marked in such a manner as to correspond with a mark on the lead screw, and successive cuts can be taken according to the number of marks on the driving plate. For example, if a triple thread were being cut, the driving plate would be divided into three equal parts, and the carriage nut could be dropped in when any of these marks corresponded with the mark made on the lead screw.

In all examples of multiple screw thread cutting, it is necessary that the position of the saddle, lead screw, and job should be marked as for cutting odd pitch threads.

Marking the Lathe

For Cutting Odd Pitch Threads

When it is not possible to cut a screw without fear of cross threading, it is necessary to mark certain parts of

the lathe, the object of this marking being to ensure commencing the cut in identically the same position on every occasion.

To mark the lathe, first have the tool set correctly in the tool holder; second, mark the position of the saddle in some manner to suit the work (by bringing it up against the loose headstock, or up to a piece of wood laid on the lathe bed); third, pull the lathe round until the nut will drop on to the lead screw quite freely; fourth, make a mark on the driving plate or lathe spindle and also one on the lead screw in a similar position. The lathe, on adjusting the tool for depth of cut, will be ready for running. After the first cut has been taken, stop the lathe and bring the saddle back to the starting position, pull the lathe round until all the marks agree, and it is then ready for another cut.

Left-Hand Threads

When cutting a right-handed thread the saddle travels towards the fast headstock; when cutting a left-hand thread it travels in a reverse direction towards the loose headstock.

In order to travel in either direction, and thereby cut right or left handed threads, a tumbler gear is generally provided in the large majority of lathes. By means of this device the motion of the lead screw can be reversed or even disengaged instantly, and no extra wheel is required.

On lathes that are not fitted with some form of reversing gear, when it is necessary to cut left-hand threads, the gear wheels can be arranged to reverse the motion of the lead screw. When a simple train of wheels only are required, then an extra wheel is placed in the train as shown in Fig. 295. The size of this wheel is of no consequence, and therefore any wheel that will gear up can be

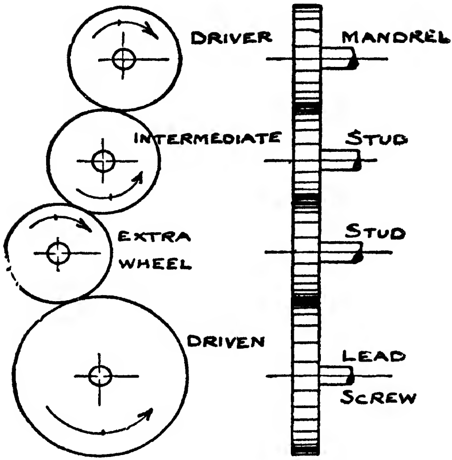


FIG. 295.—Simple Train for Left-Hand Thread.

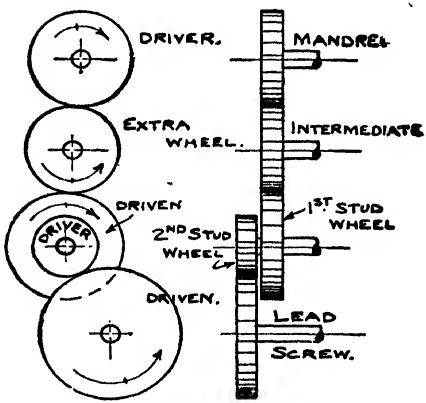


FIG. 296.—Compound Train for Left-Hand Thread.

used. A similar arrangement is needed with a compound train, and in this case the size of wheel has no influence over the ratio, and any wheel can be used that will gear up. This arrangement is illustrated in Fig. 296.

Cutting Speeds

No definite rule can be laid down for the cutting speeds of various threads, so much depending upon the size and pitch of the thread, the nature of the metal, and the skill of the turner.

In cutting fine threads on brass a high speed is desirable; in cutting gas or fine threads on iron or mild steel, the ordinary cutting speed of the metal should be approached as near as possible.

With square threads a speed considerably slower than the ordinary cutting speed of the metal is necessary; with very coarse pitch or large diameter work it is almost impossible to drive too slowly on the average general lathe.

Internal Threads

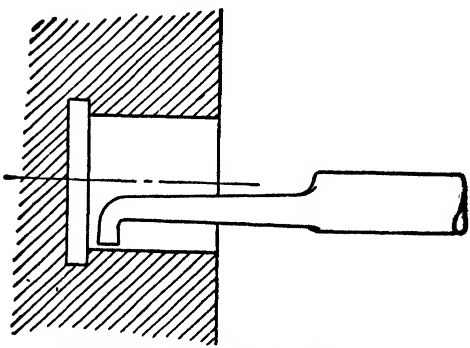


Fig. 297.—Internal Screw Cutting.

When it is necessary to cut internal threads in blind holes, or where it is not possible to run the tool right through the hole, it is necessary to bore a recess at the bottom of the hole as shown in Fig. 297. This hole is bored to the same diameter as the outside of the thread, and slightly wider than the groove in the thread.

Screw-Cutting Tools

Tools for cutting threads in the screw-cutting lathe may be classified according to whether they are to be used for cutting

Internal threads,
External threads;

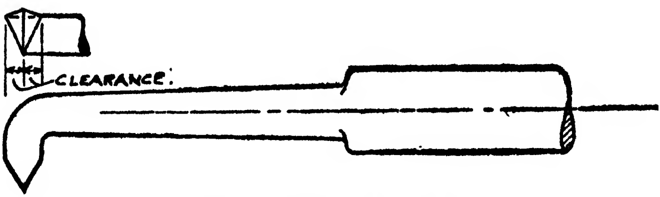


FIG. 298.—Internal Screw-Cutting Tool.

and also whether they are to cut

Vee-shaped threads,
Square threads.

For screwing internal work with a vee-shaped thread a tool similar to Fig. 298 will answer in most cases, but when the hole is very small, a round boring bar made to hold a sectional tool as shown in Fig. 299 would perhaps be more suitable.

Before adjusting a tool for internal screwing it must be

ground to the correct angle, for which purpose the screw-cutting gauge shown at Fig. 300 can be used. Care must

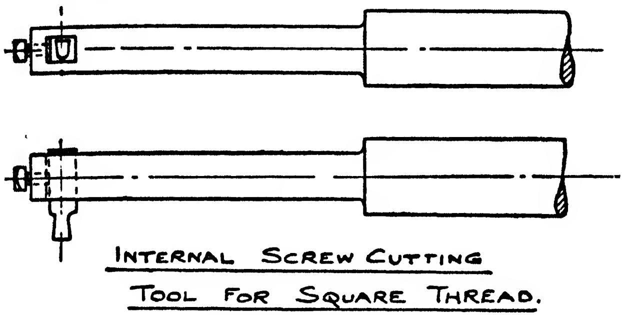


FIG. 299.—Boring Bar.

be taken to give the tool sufficient clearance so that the cutting edge is the most prominent part when the tool is set in the tool holder.

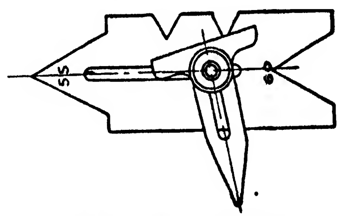


FIG. 300.—Screw-Cutting Gauge.

Rake.—For square threads when hard steel or brass is being screwed no top rake is required, but for wrought iron or mild steel a small amount of top rake will improve the cutting action of the tool. Vee-thread tools have no top or side rake.

Setting the Tool.—The correct height for all vee-thread boring tools is when the cutting edge is radial with the axis of the work. To set the tool square with the work a screw-cutting gauge can be used as shown in Fig. 301 or Fig. 302.

Testing the Thread.—Internal work screwed in the lathe cannot as a rule be removed for testing purposes, and therefore if the actual screw cannot be used to test for depth, then a gauge must be provided. The most satisfactory way to screw threads to the exact depth is to slightly counterbore the hole, say about $\frac{1}{32}$ of an inch, and

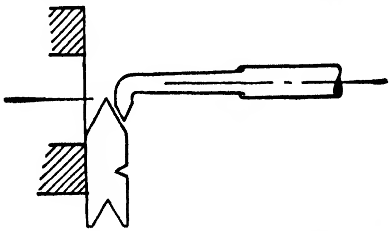


FIG. 301.—Setting Screw-Cutting Tool.

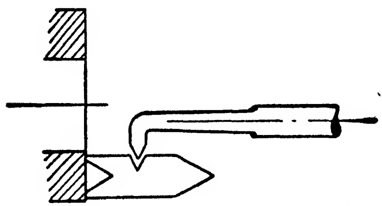


FIG. 302.—Setting Screw-Cutting Tool.

bore this small depth to a diameter equal to the outside diameter of the screw.

When screwing gas or Whitworth threads the tops and bottoms of the thread can be rounded off with an inside chaser, and when approaching the correct size the screw or gauge should be frequently tried in the hole to ensure a good fit. When testing great care must be taken to see that the first thread is not thicker than the rest, because on the commencement of a cut the tendency is for the

tool to be pushed away from the work, owing to on'y one side of the tool cutting.

Vee Threads

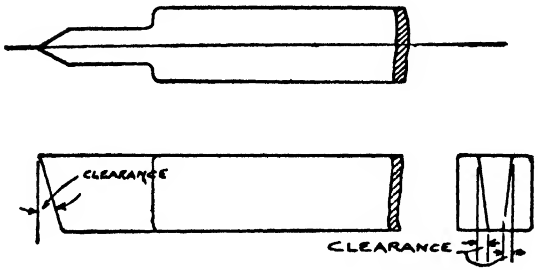


FIG. 303.—Screw-Cutting Tool Vee Threads.

A common form of vee-thread tool is illustrated at Fig. 303. When grinding to shape it is usual to give about 15° clearance, slightly round the point, but leaving the cutting edge perfectly flat. The necessary side set or inclination necessary to suit the pitch of the thread is given to the tool when grinding it, or if a round section tool is used the tool can be twisted to the required angle. This angle is often judged by the turner, but if large bolts are being threaded the angle can be found and the tool set, as shown in Fig. 304. The circumference of the core and the pitch being marked off, a diagonal line will give the rake the tool must be set to.

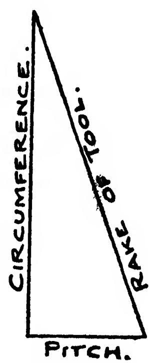


FIG. 304.
Inclination of Tool

To set the tool square with the work and ready for

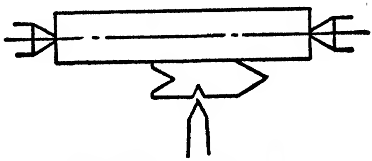


FIG. 305.—Setting Tool.

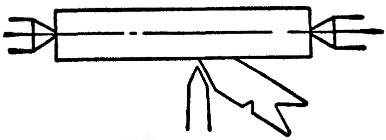


FIG. 306.—Setting Tool.

screw-cutting operation, the methods shown at Fig. 305 and Fig. 306 can be adopted.

Square Threads

The most useful form of square-thread screw-cutting

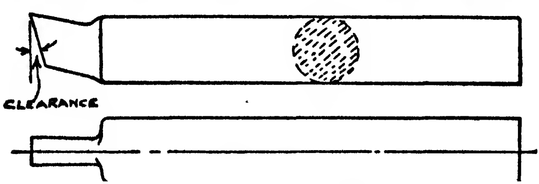


FIG. 307.—Square-Thread Tool.

tool is made from round section steel, as shown in Fig. 307, which can be held in a tool holder similar to Fig. 308. The advantages of this form of tool are: that no

forging is required; the tool can be ground from the solid bar; it can be set at any inclination, and is easily adjusted.

The correct setting of a tool for cutting multiple threads is most important, the inclination varying both with diameter and lead. Fig. 309 shows the tool angle for threads of two different diameters and various leads. The circumference of the work should be taken on the core diameter. When cutting threads the correct angle should be drawn on paper, and the angle or screw-cutting gauge set to the inclination the tool can then be set quite accurately.

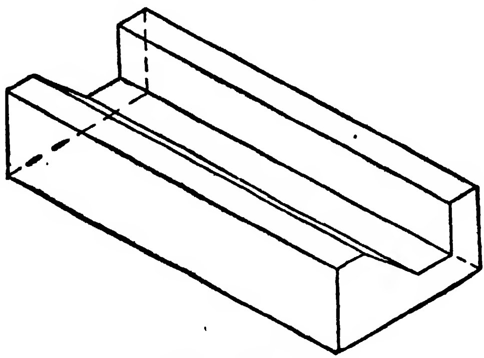


FIG. 308.—Tool Holder.

Position of Screw-Cutting Tools

A number of square thread screw-cutting tools are shown in various positions in Fig. 310. The position shown at A is one in which the centre of the cutting edge is level with the axis of the screw, the cutting edge itself being at right angles with the sides of the thread; this position is incorrect, and in addition to cutting a thread space too wide, it will result in the bottom of the thread space being turned concave. The position at B is also wrong. Here again the thread space will be

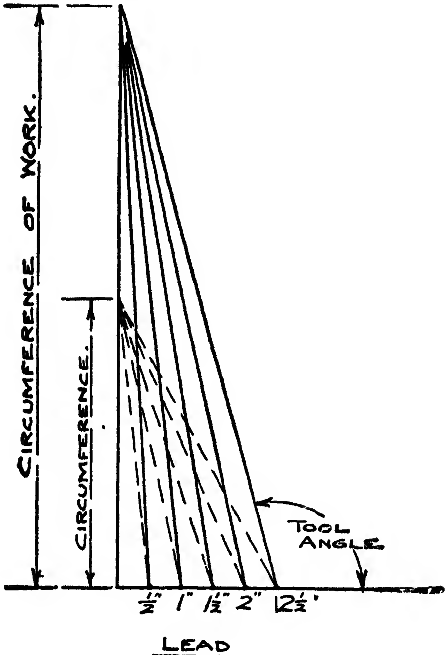


FIG. 309.—Inclination of Screw-Cutting Tools.

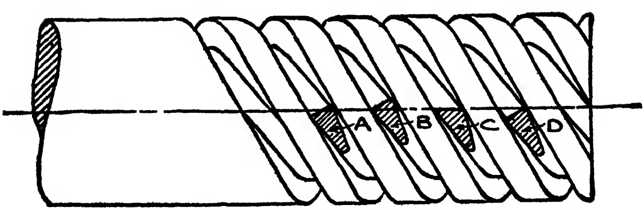


FIG. 310.—Positions of Tools.

too wide, and the tool will have a tendency to dig in the work. The same objections apply to D. The correct position for a square thread screw-cutting tool, whose width is half the pitch of the screw being cut, is the one shown at C. Here the cutting edge of the tool is exactly level and parallel with the axis of the screw, sufficient inclination and clearance being given to enable it to clear the sides of the thread when cutting from the outside of the thread to the root diameter.

When the thread is of very coarse pitch or lead, one corner of the tool is weak, and it is then necessary to set the tool to the position at A, in which case the width of the tool depends upon the pitch or lead and the diameter of the work. To find the width of the tool the following formula can be used:—

$$\text{Width} = \frac{\text{cosine of angle} \times \text{nominal pitch}}{2}.$$

When cutting wide threads it is advisable to use two tools, one for roughing out nearly to depth and about half the full width, the other to finish the thread accurately to size. When cutting the full width with one tool it has a tendency to tear the sides of the thread and leave a rough surface. When the thread is started, care must be taken to see the first thread is being cut correctly, as there is a tendency to push the tool away from the thread.

The termination of a thread is of importance owing to the possibility of breaking the tool. Vee-shaped threads can be terminated in a groove turned in the metal without weakening the bolt or screw to any great extent. Square threads can be finished in flat-bottomed holes.

CHAPTER XV

CAPSTAN AND TURRET LATHES

The capstan and turret lathes are designed for the economic production of a wide range of articles that have to be made in small or large numbers.

A capstan lathe by Herbert of Coventry is shown in Fig. 311 and a turret lathe by the same concern features in Fig. 312. These machines may be used for producing articles from drawn and extruded bar, from forgings, castings, and hot pressings. With two tool posts on the cross slide and six tool positions in the hexagon turret it is possible to bring eight or more tools into operation at each setting of the workpiece, without disturbing the tools. The general layout of the machines follows the modern tendency of having an all-geared headstock and either a single pulley or individual motor drive according to the buyer's requirements. If so desired, the old type cone pulley machine may be obtained. The general details relating to the turret lathe are as follows:—

Headstock.—Eight spindle speeds in either direction is instantly available, the changes being made through sliding gears and friction clutches. The latter are controlled by two levers in the front of headstock.

Spindle.—The spindle is of the flanged type so that chucks may be bolted directly in position. The bearing's shells are of bronze with white metal liners.

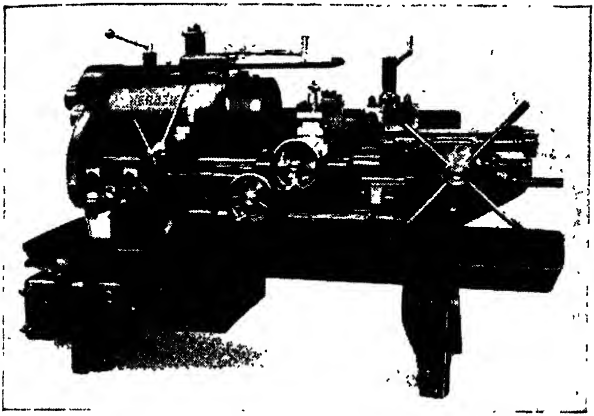


FIG. 311.—Herbert's No. 4 Capstan Lathe.
(By courtesy of Messrs A. Herbert Ltd., Coventry.)

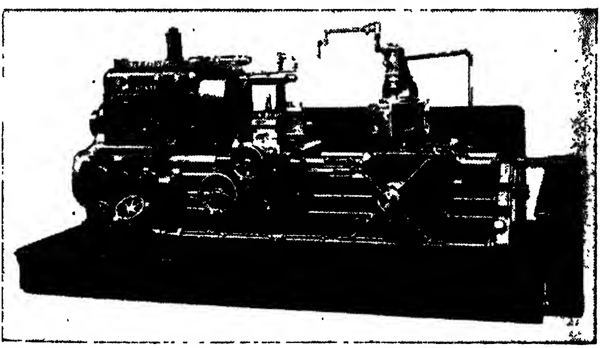


FIG. 312.—Herbert's No. 8 Preoptive Combination Turret Lathe.
(By courtesy of Messrs A. Herbert Ltd., Coventry.)

Feeds.—The feed box provides six changes of automatic feed in both directions for surfacing and sliding. Changes are made by finger-controlled pilot wheels and levers, whilst the feed mechanism is protected by a clutch which slips when overloaded. The engagement and stopping of the cross slide or carriage is by levers on the aprons.

Stops and Indicators.—Stops and indicators are fitted to the turret cross slide and carriage so that accurate dimensions can be readily duplicated.

Extras.—When required, a chasing or taper turning attachment can be obtained.

Bar feed.—When producing work from the bar a bar feed mechanism, not shown, is required.

Holding the Workpiece.—The method adopted to hold the workpiece will vary. Bars are used, gripped by means of a spring collet; many castings, forgings, and hot pressings are held in a three or two jaw chuck as shown in Figs. 235 to 237. In some instances it becomes necessary to design a special fixture; irrespective of the method, care should be taken to ensure that the component is not distorted when clamped in position.

The Herbert hand and pneumatically operated chucks fitted with a spring collet are shown in Figs. 313 and 314.

Hand-Operated Type.—The mechanism is totally enclosed in a body A, which is bolted to the headstock casting. To release the work the lever C is pulled towards the operator and pushed towards the machine to grip it.

The lever C is fixed to a small cross shaft which carries the operating pinion D. Meshing with this pinion is a gear segment cut on the periphery of the sleeve E. Two helical grooves are cut in this sleeve and the phosphor bronze gluts F, which are bolted to the body, fit in them.

It will be seen that the movement of lever C is transformed into a rotary and lengthwise movement of sleeve E.

This lengthwise movement is transmitted to the ball-operating sleeve G by one of two thrust washers, the rear one of phosphor bronze and the front one a ball thrust to take the closing load.

The bore of the ball-operating sleeve has two diameters connected by a cam surface and in the position shown the smaller diameter is being used to lock the operating

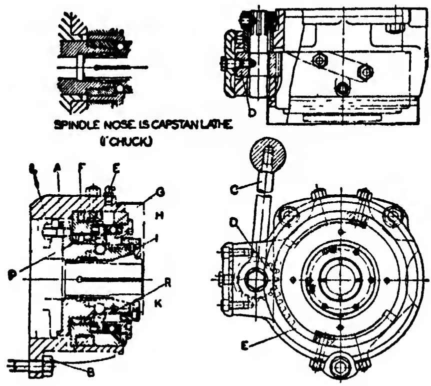


FIG. 313.—Manually-Operated Bar Chuck.
(By courtesy of Messrs A. Herbert Ltd., Coventry.)

balls H and the chuck in the closed position. The thrust through the balls moves the collet sleeve over the conical portion of the collet or conical holders and thus grips the work.

As the operating lever C is reversed the sleeve E is turned the opposite way, resulting in reversal of the ball-operating sleeve G which exposes the larger internal diameter to the operating balls H and, due to spring action, the chuck opens.

The collet butts against a screwed cap which is adjustable to accommodate slight variations in the diameters of work being held.

An operator can easily " feel " the correct adjustment on the hand chuck and " see " it on the air chuck. By complete removal of the cap the collet or conical holders can be removed.

It will be seen from the section drawing that the revolving parts on the spindle make contact only with the stationary body at one point, where the two thrust washers provide ample bearing.

Removal of the chuck is quite a simple matter so that change over to self-centring chucks, faceplates, or fixtures can be carried out with very little loss of time.

Removal or Attachment of Dead-Length Bar Chucks.—Drop lever C to lowest position (remove air pipe on air chuck). Remove cap K after unscrewing lockscrew and withdraw collet or conical holders. Remove nuts or screw B which fasten the body to the headstock casting.

Withdraw the body leaving the spindle nose assembly intact. Make sure that no operating balls are lost. Remove the nuts L to detach the spindle nose assembly (the 1-in. size has the collet sleeve screwed direct to the spindle).

The assembly is just the reverse of the above operations except that to hold the operating balls in position they should be first coated with vaseline.

Air-Operated Type.—The construction of the air-operated chuck is roughly identical with the hand-operated type but the power is supplied by the piston M directly connected to a lever N which moves the sleeve E endwise. The chuck is controlled by a hand valve. An oiler is provided for the pneumatic mechanism and the air is

filtered. When necessary the filter can be taken out and cleaned by removing two nuts on the underside.

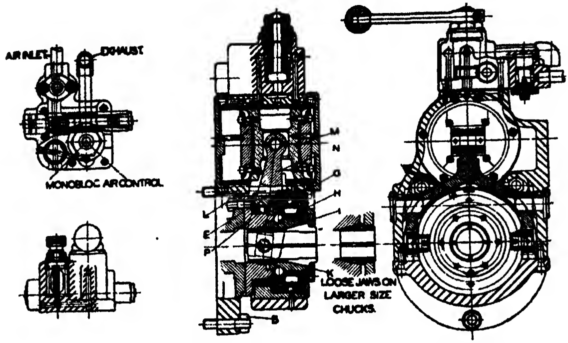


FIG. 314.—Air-Operated Bar Chuck.
(*By courtesy of Messrs A. Herbert Ltd., Coventry.*)

Maintenance.—The chucks should be dismantled and well cleaned once every four working weeks. When reassembling the parts, the surfaces should be well covered with a high quality grease. Grease nipples are fitted and the grease gun should be used at frequent intervals when the chuck is closed. The oiler for the pneumatic mechanism should be filled at regular intervals.

Oversize Spring Collet Attachment

In Fig. 315 is shown an attachment which can be fitted to the spindle nose or with slight modification to a standard bar chuck. Then, so far as short-length work is concerned, the holding capacity of the collet on the outside of the workpiece is roughly doubled.

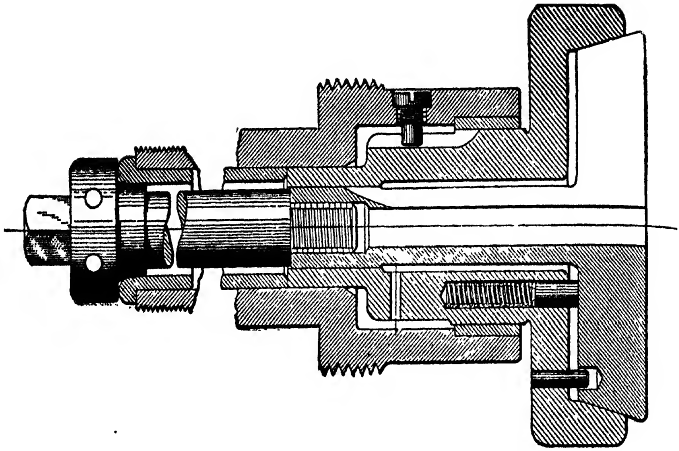


FIG. 315.—Oversize Spring Collet Attachment.

Boring and Surfacing Lathes

In Fig. 316 is shown a modification of the normal centre lathe for production work involving boring and surfacing. In this arrangement the tailstock is dispensed with and on the cross slide is mounted an hexagonal turret. The machine shown has a swing of 36 in. and is fitted with a large chuck. When necessary one may design and fit a fixture for holding the component. Normally the lathe is not designed for screw-cutting, but if it should be necessary the makers can incorporate the required lead screw and connect this to the gear box and apron. A set up for nine operating shoes on the face plate is shown in Fig. 317 whilst a few of the various types of tool holders feature in Fig. 318.

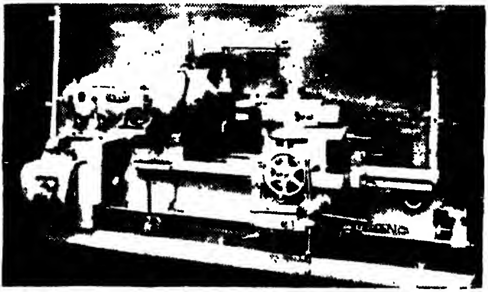


FIG. 316.—Turning, Facing, and Boring Lathe.
(*By courtesy of Messrs J. Lang & Sons Ltd., Johnstone.*)

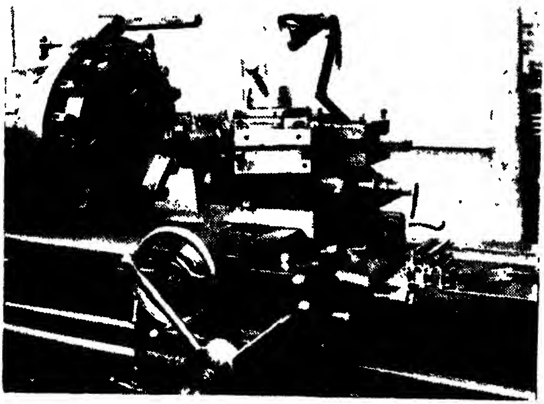


FIG. 317.—Turning, Facing, and Boring Lathe. Note Workpieces in Machine Bed.
(*By courtesy of Messrs J. Lang & Sons Ltd., Johnstone.*)

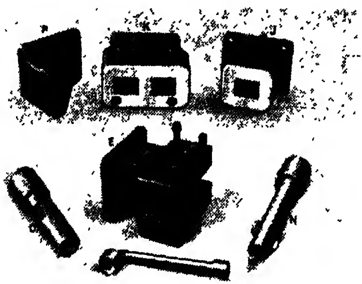


FIG. 318.—Tool Holders and Boring Bar.
(*By courtesy of Messrs J. Lang & Sons Ltd., Johnstone.*)

The boring and surfacing lathes shown are by Messrs Lang & Sons Ltd., of Johnstone, and as the machine is so closely akin to the lathes already mentioned further detail appears unnecessary. These remarks apply to the tools used (also see under Turret Tools) and the method of holding the components.

CHAPTER XVI

CAPSTAN AND TURRET LATHE TOOLS AND HOLDERS

THE successful operation of capstan and turret lathes depends upon well-made tools having durable edges plus skill in arranging each layout, so that the surplus metal can be removed in the shortest space of time consistent with an economic run. The general shapes of the single-point tools as are used on bulk of the machine tools and found in the general engineering shop have been given in the chart, Fig. 208, facing page 243, hence for space reasons the information is not repeated.

With this class of production machine, engaged either on small or large batches, very careful attention should be given as to the relative merits of the various classes of cutting medium, the cemented carbides, Stellite, or a tool made in one of the high-speed steels. The above is essential when aiming for the lowest all-in cost of production which takes into account the daily output, the time the machines are standing idle, regrinding and setting, the initial cost of the equipment, housing, repair, and power charges.

As the bulk of the capstan and smaller turret lathes are operated by women and men coming within the general category of semi-skilled, great attention should be paid to the setting and the choice of speed and feed so that after each resharpening a long run is assured. Hence excessive overhang of any tool should be avoided.

Turret Tools

A number of the tools or tool holders as are fitted in the turret of a capstan or similar lathe are listed below, but one should realise that they are representative only and that other designs will be encountered.

The Drill Chuck.—It is often necessary to hold small parallel shanked drills in the turret, and one method is to use a drill chuck as shown in Fig. 319. This chuck may also be used for holding the standard centre drill as shown in Fig. 255, page 290.

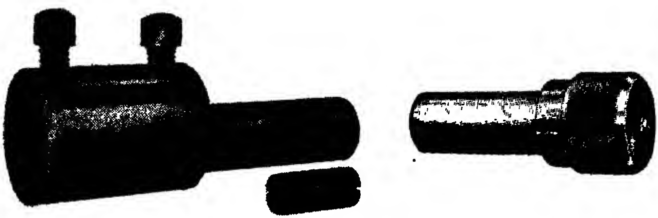


FIG. 319.—Drill Holder and Drill Chuck.
(By courtesy of Messrs A. Herbert Ltd., Coventry.)

FIG. 320.—Sleeve for Taper Shank Drills when used in Turret of a Capstan Lathe.
(By courtesy of Messrs A. Herbert Ltd., Coventry.)

As an alternative to the drill chuck in Fig. 256 or Fig. 319 the holder in Fig. 319, having a split bush for each drill size, may be used. If using a taper shank drill, then the sleeve in Fig. 320, having a bore of the desired Morse taper and the outside diameter to suit the hole in the turret, is chosen.

FIG. 321 —Flat Centring Drill and Bush.

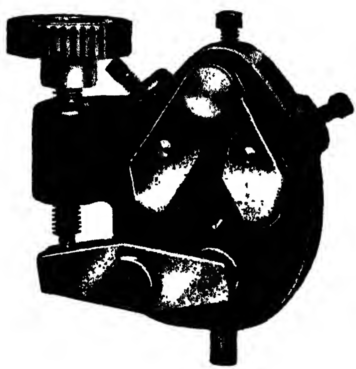


FIG. 322.—Roller Steady Centring Tool.

(By courtesy of Messrs A. Herbert Ltd., Coventry.)

Centring Drill.—A flat type of centring drill is shown in Fig. 321 and is used to provide a true start for the standard type of twist drill. Another type of centring tool is illustrated in Fig. 322 and here the bar is supported by means of rollers, and the standard centre drill in Fig. 255 is usually held in the bush. The action of the three rollers is to centre and steady the bar and thus avoid breakages of the drill.

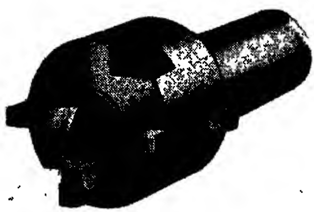


FIG. 323.—Combined Centring and Facing Tool.
(*By courtesy of Messrs A. Herbert Ltd., Birmingham.*)

Combined Centring and Facing Tool.—A combined centring and facing tool is shown in Fig. 323, and this class of equipment is used extensively on bar work. When desired the facing cutters can be arranged to cone or otherwise form the end of the bar.

Roller Steady Ending Tool.—A tool having roller steadies and a form tool for shaping the end of a bar or component is shown in Fig. 324.

Roller Box Turning Tool.—A typical example of a roller box turning tool is shown in Fig. 325 and the design shown is for clamping direct to the face of the turret.

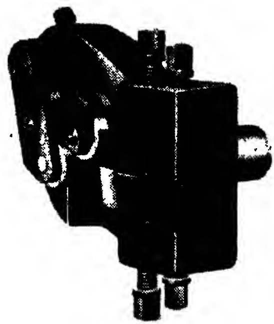


FIG. 324.—Roller Steady Ending Tool.
(By courtesy of Messrs A. Herbert Ltd., Coventry.)

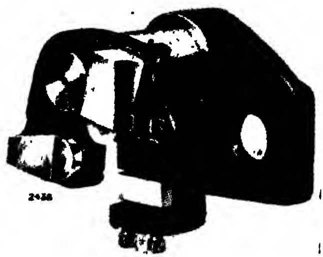


FIG. 325.—Roller Box Turning Tool.

Another design has a shank which fits in the bore of the turret. The position of the roller in relation to the cutting edge of the tool may be in advance or behind, the exact position depending upon the machining operation.

Vee Steady Tool Box.—A vee steady tool box used chiefly on brass work features at Fig. 326, and is used for much the same purpose as the roller box shown above. It

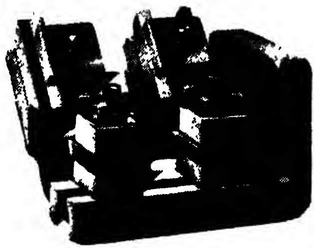


FIG. 326.—Vee Steady Tool Box.
(By courtesy of Messrs A. Herbert Ltd., Coventry.)

may be designed, as shown, for direct clamping to the turret face or with a shank for holding in the bore of the turret.

Boring Bars.—A standard type of boring bar of steel, hardened and ground, is shown in Fig. 327. It is designed

FIG. 327.—Boring Bar for Adjustable Floating Cutters.
(By courtesy of Messrs A. Herbert Ltd., Coventry.)

to take cutters of the floating type. Others having inserts of the square or round cross section are in constant use.

Boring and Facing Head or Block.—The boring and facing head as illustrated in Fig. 328 is used in conjunction with the boring bar. According to the class of tool held

in the head it may be used for boring, facing, or forming. A pad bolt and key holds the head in position on the boring bar.

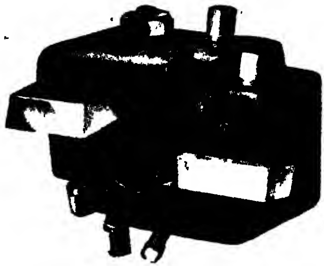


FIG. 328.—Boring and Facing Head or Block.

Extension Holder.—In a number of instances the tool layout renders it necessary to use the boring bar extension

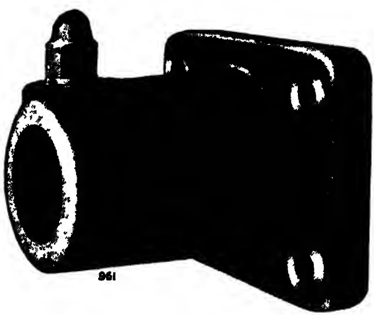


FIG. 329.—Boring Bar Holder or Extension Piece.
(By courtesy of Messrs A. Herbert Ltd., Coventry.)

holder (Fig. 329). The holder itself is clamped to the turret face and the boring bar is held in the extension piece by means of a pad bolt; if heavy cuts are to be taken then

it often becomes desirable to fit a key in the extension and cut a corresponding keyway along the boring bar.

FIG. 330.—Knee Tool Holder.
(By courtesy of Messrs A. Herbert Ltd., Coventry.)

Knee Tool Holder.—In Fig. 330 is shown a knee tool holder in which may be fitted a standard boring bar so that turning and boring may be taking place simultaneously.

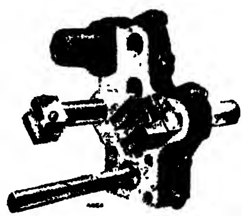


FIG. 331.—Combination Tool Holder.

Combination Tool Holder.—A combination boring, turning, and facing tool arrangement is shown in Fig. 331, and with some machining jobs three or more tools

may be engaged in cutting at the same time. It should be appreciated that the actual combination will depend upon the component to be produced.

Circular Chasing and Recessing Tool Holder.—A circular chasing and recessing tool holder is shown in

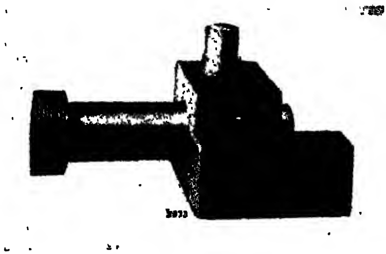


FIG. 332.—Chasing or Recessing Tool Holder.

Fig. 332 and is held in the cross slide tool post, and may be used when cutting either internal or external threads on a capstan or turret lathe.

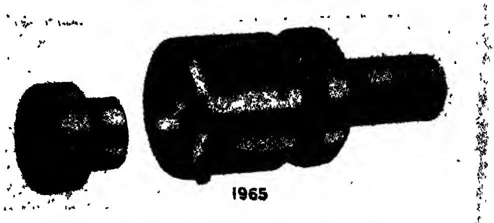


FIG. 333.—Button Die and Tap Holder.

Die and Tap Holder.—The button die and tap holder is shown in Fig. 333 and is of the reversing type.

Self-Opening Die-Heads.—Three types of self-opening die-heads are shown in Figs. 334 to 336 and are used on

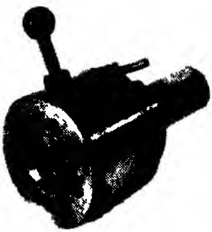


Fig. 334.—Coventry Self-Opening Die-Head.

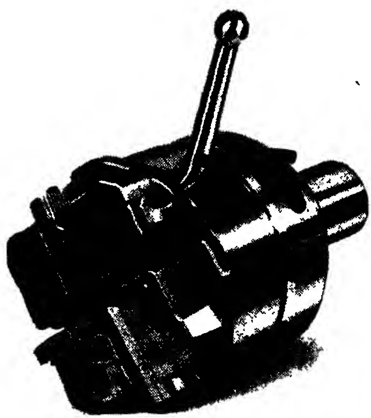


FIG. 335.—Tangel Die-Head.
(By courtesy of Messrs A. Herbert Ltd., Coventry.)

capstan, turret, and automatic lathes. At the end of the stroke the chasers open so that it is unnecessary to reverse the machine and unwind the die-head off the workpiece as is required when using a button die.

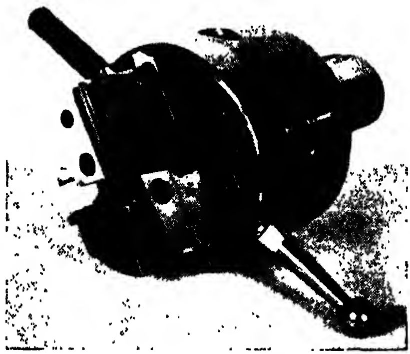


FIG. 336.—Tangel and Tangar Die-Head.
(*By courtesy of Messrs A. Herbert Ltd., Coventry.*)

Taper Turning Tool.—Fig. 337 is a taper turning tool that is attached to the turret and is used for machining the taper on such articles as mud and fusible plugs. The tool carries a revolving centre which operates a rack and pinion and may be adjusted for different tapers. The workpiece is steadied by the revolving centre and as the capstan slide is fed forward the axial movement of the centre is arrested. Hence further forward movement of

the slide causes the cutting tool to advance and machine the taper.

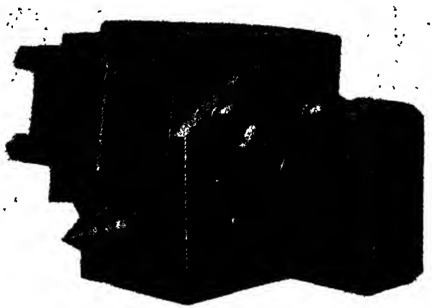


FIG. 337.—Taper Turning Tool for Capstan Lathes.

Examples of Capstan or Turret Lathe Work

A few examples showing the type of work that can be conveniently done on the capstan or turret lathe are given in Fig. 338.

It will be appreciated that the general layout for either of these machines will be very much the same.

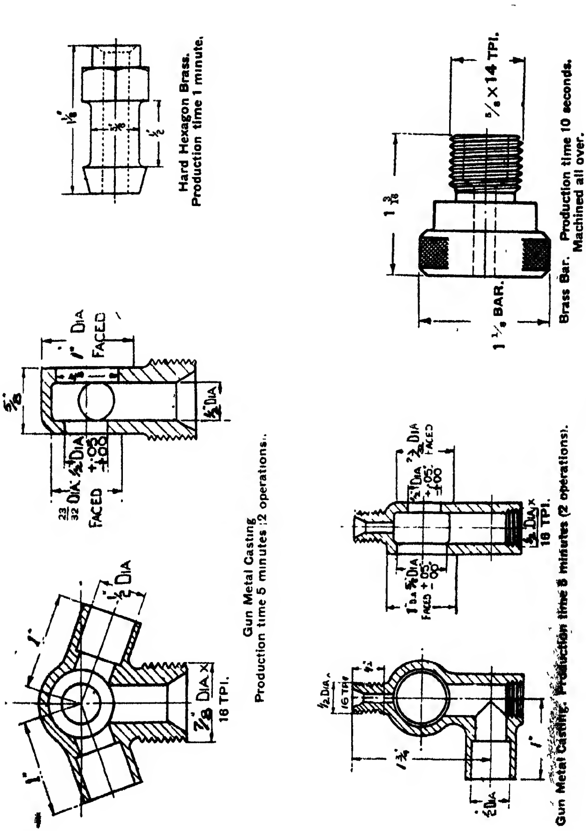

Hard Hexagon Brass.
Production time 1 minute.
Gun Metal Casting
Production time 5 minutes (2 operations).
7/8 DIA X 16 TPI.
1" DIA FACED
23/32 DIA FACED
Brass Bar. Production time 10 seconds.
Machined all over.
1 1/8 BAR.
5/8 X 14 TPI.
Gun Metal Casting. Production time 5 minutes (2 operations).

FIG. 338.

Turret Lathe Operations

The examples of turret lathe operations given in Figs. 339 to 345 show the tool positions and general arrangement as applied to the Hartness flat turret lathe. It will be appreciated that the layout on the usual hexagonal turret lathe will be much the same.

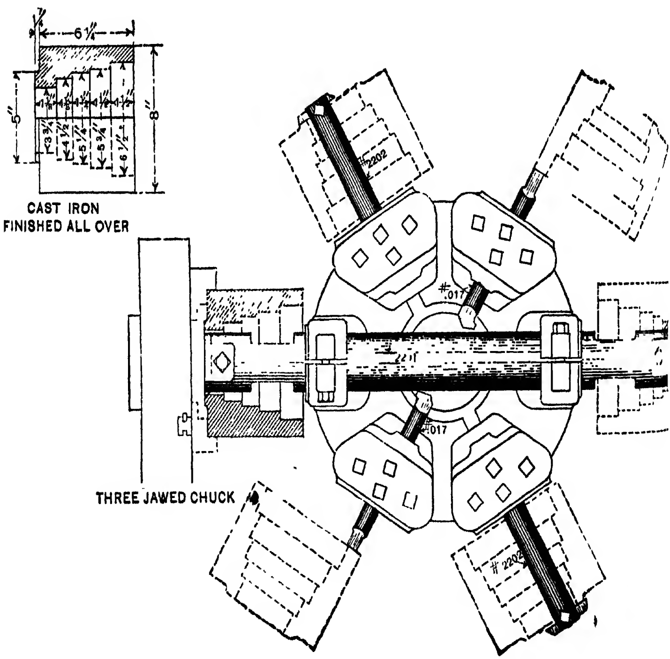


FIG. 339.—Finished in Two Operations—First Operation.

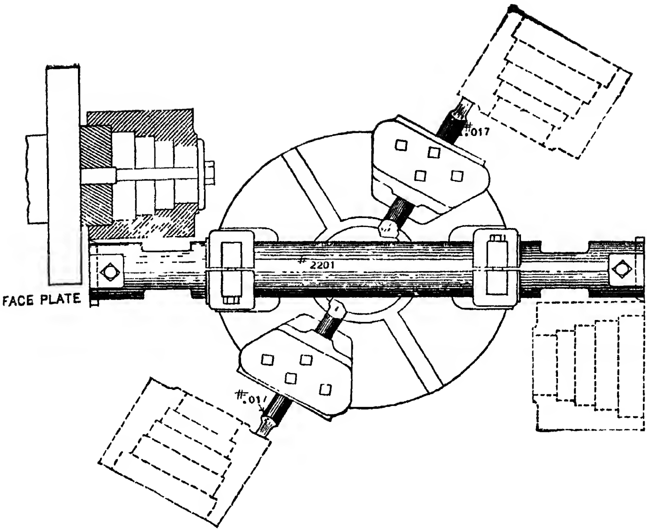


FIG. 340.—Finished in Two Operations—Second Operation.

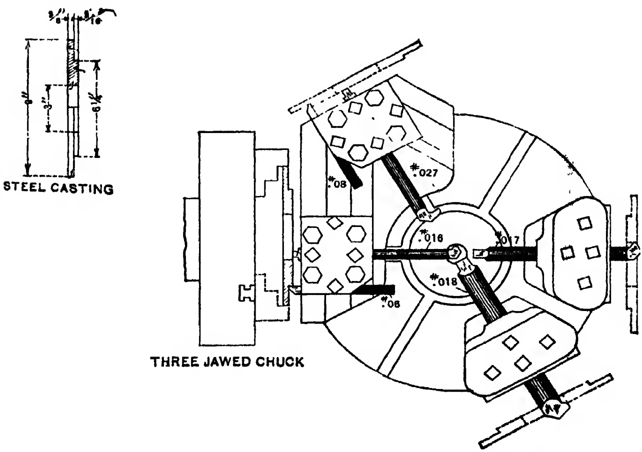


FIG. 341.—Finished in Two Operations—First Operation.

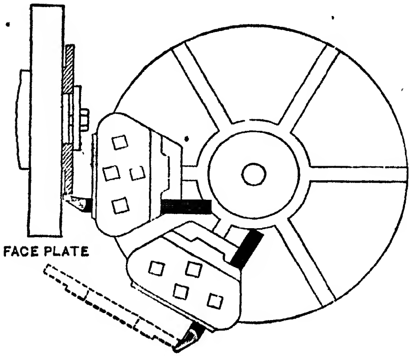


FIG. 342.—Finished in Two Operations—Second Operation.

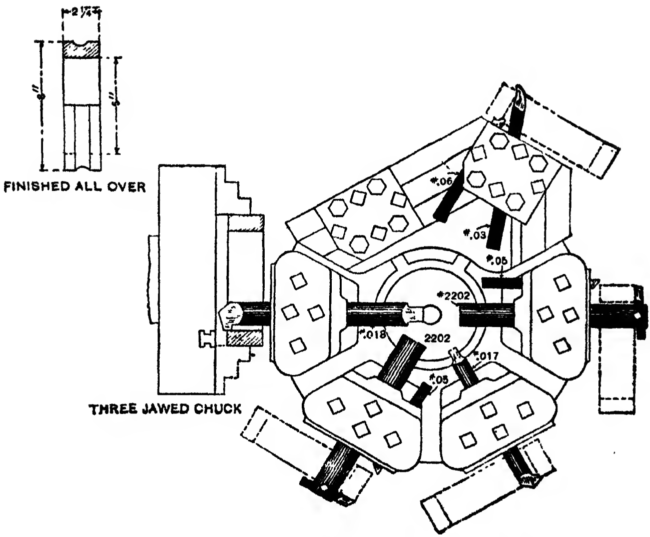


FIG. 343.—Finished in Two Operations—First Operation.

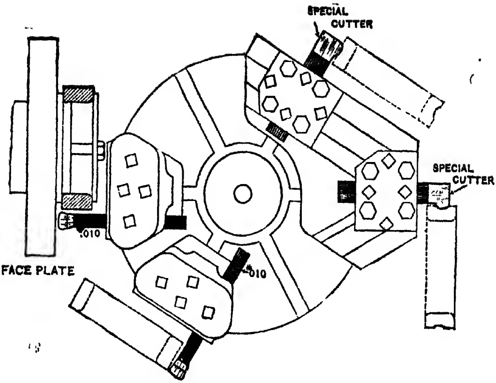


FIG. 344.—Finished in Two Operations—Second Operation.

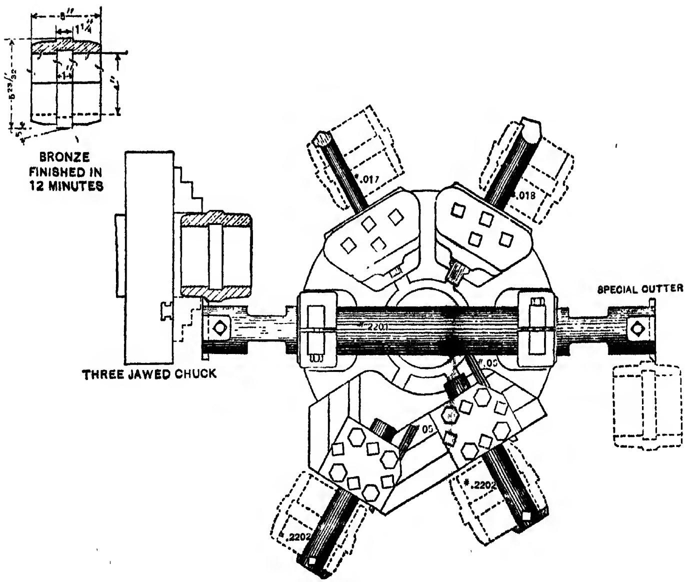


FIG. 345.—Finished in One Operation.

CHAPTER XVII

PLAIN AND UNIVERSAL MILLING

THE operation of milling, or the cutting of metal by means of revolving mills, has become of great importance in recent years. To a large extent the milling machine has displaced the planer and the shaper, and to a smaller degree even the lathe. The great obstacle to the more general use of the milling machine has been the initial cost and upkeep of cutters. It has been the practice for some firms to make their own, and this, often having to be done by hand, proved a very expensive method. Since high-speed steel cutters have been produced by specialist concerns at reasonable prices, with the guarantee that they will cut efficiently, and the knowledge that defective cutters will be replaced free of charge, the use of the milling machine has increased to a remarkable extent.

With all its advantages for rapid and economical shaping of metals, there are some operations which can still be done cheaper and quicker by means of the planer and shaper. Hence for some classes of work the latter machines will always be required.

It is owing to the increasing importance of milling machines, and their extended and more general use, that so many pages are being devoted to illustrating the various operations that can be performed by this type of machine tool.

The advantages of milling over other methods of machining is due to the fact that exact reproduction of intricate

forms can be obtained quite automatically and independent of the operator, and when a large number of parts are to be produced in duplicate, this is, of course, of supreme importance to the manufacturer.

With the passing of time quite a number of designs of the milling have been evolved to meet the various manufacturing requirements. Very roughly they may be grouped into the horizontal, vertical, and universal types.

Plain Milling Machines.—These machines can be used for a great variety of general milling work. They are made to be easily and quickly adjusted, and are used extensively on general production, tool, and jobbing work. They are arranged, as a rule, in such a manner that the table and work can be fed automatically or by hand in either direction horizontally, the table being lifted or lowered by hand only. The table is arranged to move at right angles to the arbor of the machine, and cannot be swivelled in any way.

Vertical Milling Machines.—The vertical milling machine is designed so that the spindle which carries the cutter revolves and cuts while rotated in a vertical position, the work being fed horizontally, vertically, or by a circular motion to the cutter.

An example of a vertical machine by Herberts of Coventry is shown in Fig. 346.

The principal features of this machine are the special provisions made for automatic vertical movements, which can be adjusted slow or quick; the provision for attaching large surfacing cutters to the spindle nose direct; the fact that all gears are enclosed, and all movements governed by convenient hand wheels, with adjustable index discs to all motions; automatic stops to all feeds, with the longitudinal and cross-feed nuts made adjustable for wear, and fitted with ball thrusts to the feed screws.

For circular work, a circular table with automatic feed in either direction, and automatic stops, is fitted to the machine. A rotating square table, which can be used for

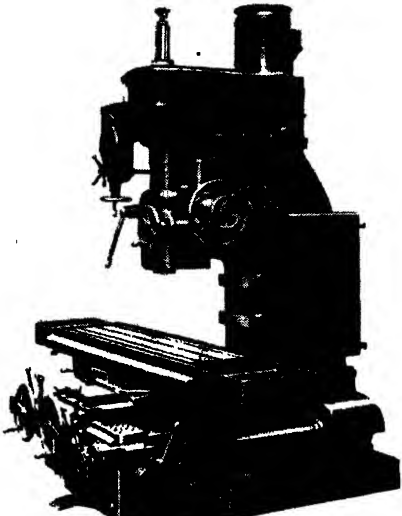


FIG. 346.—Herbert's Vertical Milling Machine.
(By courtesy of Messrs A. Herbert Ltd., Coventry.)

bulky work which cannot be covered by the traverses of the machine, can also be fitted to the table, and by means of this attachment one side of a piece of work can be milled, and the table rotated through 90° or 180° as required to do the other sides.

Examples of Vertical Milling Work

The following illustrations are taken from work done by one of Messrs Alfred Herbert's vertical milling machines.

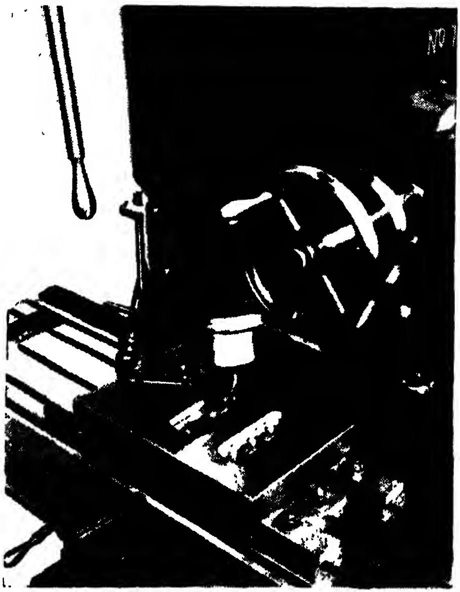


FIG. 347.—An Example of Milling on the Vertical Machine.
(*By courtesy of Messrs A. Herbert Ltd., Coventry.*)

Recessing.—An example of the use of the end mill is shown in Fig. 347. This illustrates the method of using the end mill for cutting out recessed portions of castings,

and for general work of a similar character. A great amount of work can be accomplished in this manner that can be done in no other way. The actual job being performed is the chasing saddle of a combination turret lathe.

Face Milling.- The illustration, Fig. 348, shows the

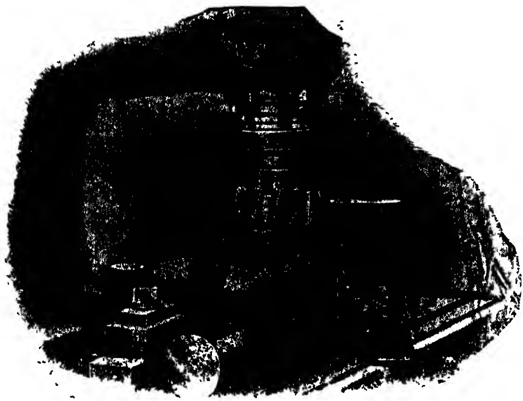


FIG. 348.—Milling at Different Levels.

use of a face cutter on work having a number of facings to be machined at different levels.

The casting shown being operated upon is the feed box of a capstan lathe, and there are five facings to be milled off at three different levels. Such work is very rapidly performed on vertical milling machines.

Facing with Vertical Mill.—Fig. 349 shows a very good example of facing work by means of a spiral side mill. Very rapid and accurate work can be turned out by this arrangement.

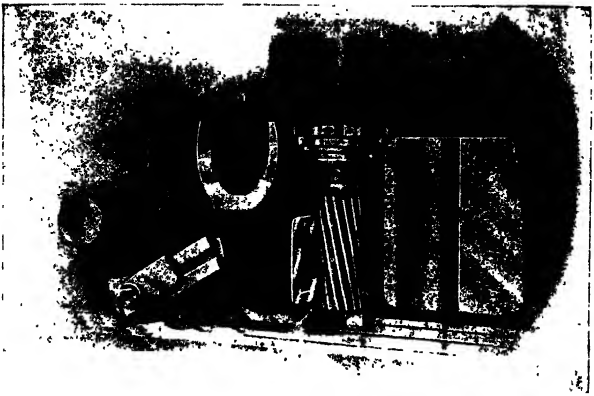


FIG. 349.—Facing with Vertical Mill.

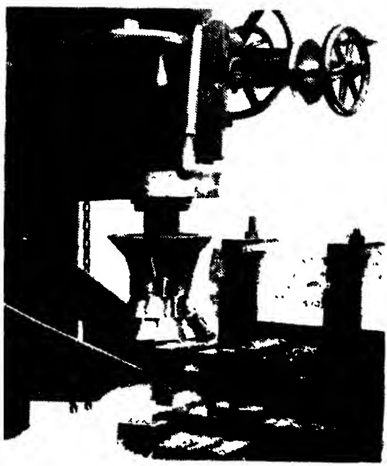


FIG. 350.—Illustration of Form Milling on Vertical Machine.
(By courtesy of Messrs A. Herbert Ltd., Coventry.)

Slot Milling.—An example of slot milling is shown in Fig. 351. By adopting this method for slotting work, it is possible to do jobs which would otherwise have to be done

FIG. 351.—Slot Milling.

on drilling and slotting machines. The vertical milling machine does the work from the solid at one operation, and leaves a finish much better than that produced by drilling and slotting, and, of course, very much quicker.

Circular Recessing.—Fig. 352 shows the operation of circular recessing. By fixing the work to a revolving table a large amount of work of this character can be done in a rapid and accurate manner.

Circular Milling.—A simple example of circular milling is illustrated in Fig. 353. The work, as can be seen,

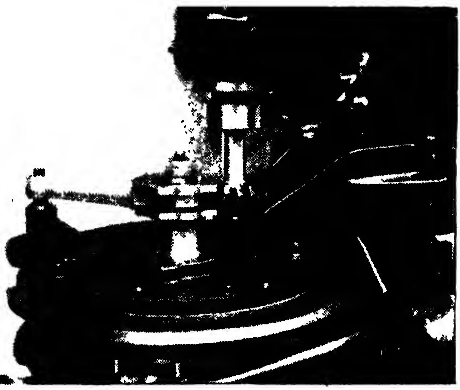


FIG. 352.—Form Milling on a Vertical Spindle Machine using the Circular Table.
(By courtesy of Messrs A. Herbert Ltd., Coventry.)

is a clutch fork, two of which are lying on the circular table. Wrought-iron and steel levers, crossheads, and rod ends are examples of similar work.

The vertical machine in Fig. 354 is by Archdales of Birmingham and is designed for the machining of light alloys. A similar type of machine is, of course, available for machining steel.

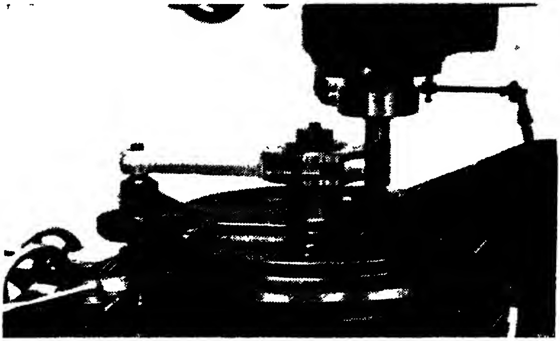


FIG. 353.—Form Milling using a Profile Cutter on a Vertical Milling Machine.
(*By courtesy of Messrs A. Herbert Ltd., Coventry.*)

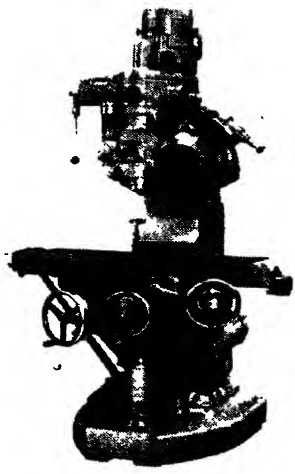


FIG. 354.—Swivel Head Miller.
(*By courtesy of Messrs Archdales Ltd., Birmingham.*)

Horizontal Milling Machines

The horizontal milling machine shown in Fig. 355 is one by James Archdales & Co. Ltd., and is intended for production work demanding continuously a large output.

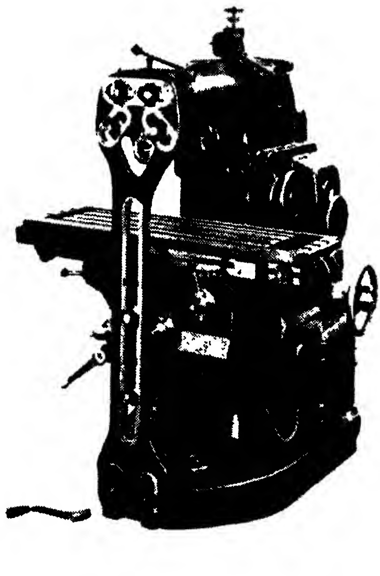


FIG. 355.—A Horizontal Miller.
(By courtesy of Messrs Archdales Ltd., Birmingham.)

The Column is a massive casting in one piece with the base, and the upper portion carries the spindle and overhanging arm. The base is lipped all round, forming a

pan. The vees forming the vertical slide give a large wearing surface.

The Gear Box is built as a separate unit, and can be removed bodily if required. The speed ranges from 30 to 600 r.p.m. in geometrical progression, and all changes are made by sliding gears, no tumbler mechanism and no sliding yokes or locking levers carrying the stress of driving being employed. The fact that there are no loose fits on the spindle renders the machine particularly free from chatter and vibration. There are no dangerous points at which the gears can lock each other while being changed. The gears all run at moderated tooth velocities and are of steel, correctly heat treated.

This machine has electrically-operated reversible feed and quick-power traverse to the longitudinal table motion; the cross and vertical traverse is hand-operated. Drive is by 5 h.p. motor housed in the column, except when D.C. is required, when the motor is mounted on a special base extension, and the machine is suitable for normal on climb milling.

The Arbor Support and Spindle.—The arbor support carries a bush-bearing for standard long arbors. The spindle is of hardened steel and bored to take the standard quick release arbors whilst the outside is machined to hold facing cutters.

The Overhanging Arm is clamped by a powerful lever from the front of the knee. It is a solid steel bar accurately ground to size. The lever can be adjusted into various positions to suit the convenience of the operator.

The Arm Brace.—The arm brace forms an outer bearing for the arbor, enabling the arbor support to be used as an intermediate bearing when using a gang of milling

cutters on heavy work. The arm brace can be adjusted in or out along the knee to suit different lengths of arbors.

Automatic and Safety Stops.—All the feeds have automatic stops in both directions.

The machine illustrated in Fig. 356 is by Herberts of

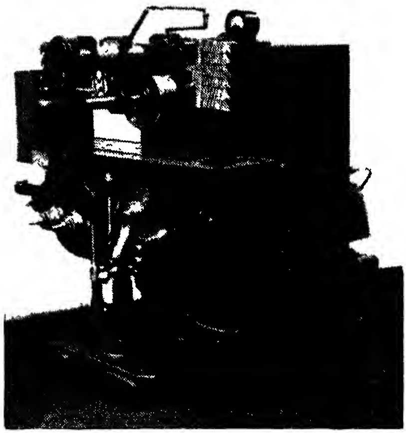


FIG. 356.—Horizontal Milling Machine.
(By courtesy of Messrs A. Herbert Ltd., Coventry.)

Coventry, and designed for both the normal and negative rake milling technique. Brief details of the machine are as follows :—

Roller Bearing Spindle runs in either direction for normal or climb cutting. Standard B.S.I. No. 739 spindle nose $5\frac{1}{16}$ in. diameter. Two large flywheels ensure

maximum efficiency at high speeds when using negative-rake cutters.

Two-Speed Motor provides 15 h.p. for negative-rake cutters and 5 h.p. for high-speed steel cutters.

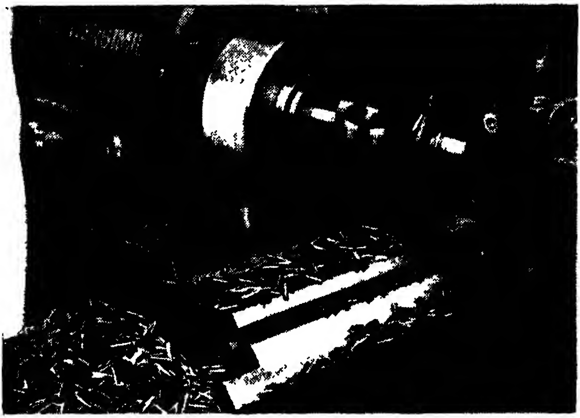


FIG. 357.—An Example of Milling on a Horizontal Machine.
(By courtesy of Messrs A. Herbert Ltd., Coventry.)

Speeds and Feeds enable wide range of work to be dealt with. Rapid changes by pick-off gears.

Automatic Feeds and Quick Power Traverse in both directions to longitudinal motion of table. Quick power traverse by independent motor. Table screw hardened and ground. Provision for eliminating backlash. "One shot" pressure lubrication to table screw, nuts, and sliding ways.

Motors and Electrical Equipment suitable for 380/420 volts, 50 cycles, A.C. supply.

Safety Features

Feed automatically disengaged if cuts and feeds likely to stall the motor are used.

Quick power traverse automatically disengaged before cutters run into work. Main spindle and cutters automatically stopped when table is traversed to end of travel in either direction for loading or unloading work.

Cover over pick-off gears electrically interlocked with starting switch.

Speeds and Feeds

H.P. of two-speed motor . . .	15 h.p. at 3,000 r.p.m.
	5 h.p. at 1,000 r.p.m.
Seven spindle speeds (at 3,000 r.p.m.) .	130 to 990 r.p.m.
Seven spindle speeds (at 1,000 r.p.m.) .	43 to 325 r.p.m.
Eight feeds (at 3,000 r p.m) . .	3⅛ to 30¾ in. per minute.
Eight feeds (at 1,000 r.p.m.) . .	1 to 10¼ in. per minute.

Universal Milling

By taking advantage of the many attachments which are provided with the universal milling machine it is possible to carry out nearly any conceivable milling operation. In addition to the automatic horizontal feed working at right angles, which is provided with the ordinary horizontal miller, it is possible on this type of machine to rotate the work and at the same time feed forward or backward at any desired angle. It is thus possible to do such work as cutting grooves in twist drills and reamers, cutting teeth on spur, helical, and bevel gears, hobbing worm wheels, and other work of a special character.

The general type of universal miller is shown in Fig. 358. In this machine the chief characteristics are:—

The Overhanging Arm, which is a solid steel bar and carries two arbor supports.

The Table is heavy and deep, with full-width bearing on the cross slide. The feed screw is of coarse pitch and unusually large diameter.

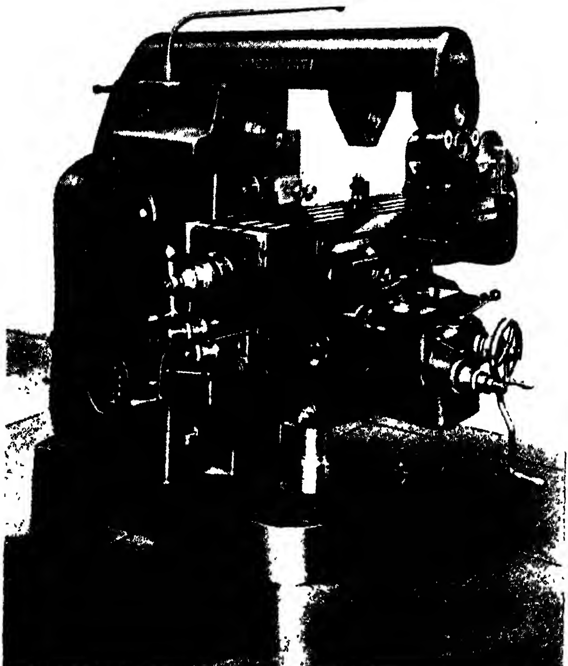


FIG. 358.—Universal Dial Type Milling Machine.

The Knee is of box section, with bearing on column carried up beyond horizontal surface. The elevating screw is telescopic and needs no hole in the floor. All movements are controlled by graduated index discs reading to one-thousandth of an inch.

The Feed is driven positively through gears, and is automatic in the longitudinal, cross, and vertical directions, all of which are controlled by automatic trips.

The Dividing Head can be set below the horizontal each way, and is of great rigidity and accuracy, and the index plates give a wide range of spacing, whilst helical grooves can be cut from roughly 1.55 in. to around 137 in. lead.

Indexing

The object of indexing is to divide the periphery of a piece of work into an equal number of parts, and thus enable the milling machine to do such work as gear cutting. For this purpose the miller is fitted with a dividing head, which may be plain or universal.

With the plain dividing head, as illustrated in Figs. 359 and 360, it is possible, by having a number of division plates, to divide work into any number of parts. The spindle of this type of head is fitted with a clutch drive, and has a taper hole. The division plates are fixed so that there is no danger of the plate moving after the work is set. The indexing bolt has a movable end, which can be changed to suit different forms of notches. The $7\frac{1}{4}$-in. head has a removable support for taking the thrust of the cutter when cutting large spur wheels. This direct method of indexing can only be applied to the universal type of head when provision is made for dropping the worm out of gear, or where it is possible to disengage the worm

wheel. The index plate is generally fitted to the front

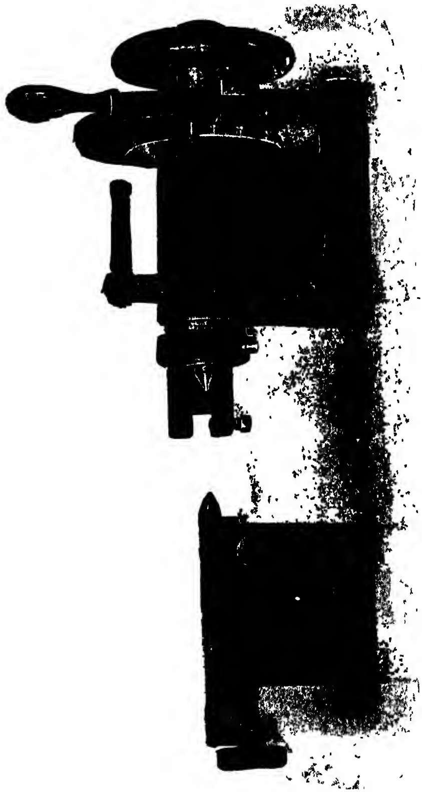


FIG. 359.—Plain Dividing Head or Indexing Fixture, 4¾-in Size.

of the spindle, and usually contains twenty-four holes or notches, equally divided. Into any of these holes or

notches a pin can be inserted, and the spindle can then be locked in that position. Thus, with a plate having 42

FIG. 360.—Plain Dividing Head or Indexing Fixture, 7¼-in Size.

divisions it is possible to divide work into equal divisions of 2, 3, 4, 6, 8, 12, and 24 parts by a very simple and reliable method.

The Universal Dividing Head

By using the universal dividing head it is possible, by taking advantage of the worm gearing, to divide work into a great number of equal parts. One of these types of head is shown in Fig. 361. This method of dividing may be termed indirect indexing.

The Indirect Method.—All indirect methods of indexing depend upon the ratio of the worm gear. This is

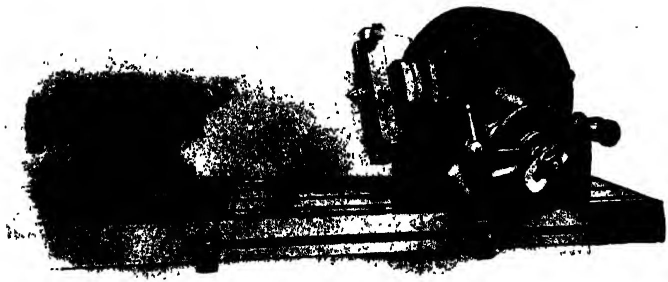


FIG. 361.—Universal Dividing Head.

generally 40 to 1, so that 40 turns of the worm are necessary to produce 1 turn of the spindle. If only a fraction of a turn of the work is required, then only a fraction of 40 turns will need to be given to the worm through the indexing handle. As the indexing spindle may be revolved by the crank, and as 40 turns of the crank make 1 revolution of the spindle, to find how many turns of the crank are necessary for a certain division of work, or what is the same thing, for a certain division of a revolution of the spindle, 40 is divided by the number of divisions which are desired. The rule then is: *Divide 40 by the number of*

divisions to be made, and the quotient will be the number of turns of the crank.

Applying the Rule.—To make 40 divisions, the crank would be turned round once to obtain each division, or to obtain 20 divisions it would be turned round twice. When it is necessary to turn the crank only part of a turn to obtain the necessary divisions, an index plate is used.

Example.—If the work is to be divided into 80 divisions, the crank must be turned half-way round, and an index plate with an even number of holes in one of the circles would be selected, it being necessary to have two holes opposite each other in the plate. If the work is to be divided into 120 divisions, an index plate should be selected which has a circle with a number of holes that will divide by three, such as 15, 18, or 21, the number on the index plate indicating the number of holes in the various circles.

The Sector.—The sector is used to avoid the counting of the holes in each partial rotation or turn of the crank, and to illustrate its use, suppose it is necessary to divide a piece of work into 144 divisions. Dividing 40 by 144 we get $\frac{5}{18}$, showing that the crank must be moved $\frac{5}{18}$ of a turn to obtain each of the 144 divisions. An index plate with a circle containing 18 holes or an aliquot part of 18 is selected, and the sector is set to measure off six spaces on an 18 circle, or eleven on a 36 circle. When the sector is set, it is secured by means of a screw. In setting the sector it should be remembered that there must always be more holes between the arms than there are spaces to be counted or measured off. After making one division the sector is moved round until the arm is against the pin in the crank.

If the angle of elevation of the spiral head spindle is changed during the progress of the work, the work must be rotated slightly to bring it back to the proper position, as

when the spindle is elevated or depressed the worm wheel is rotated about the worm, and the effect is the same as if the worm were turned in the opposite direction.

Index Table for Use with the Dividing Head of Milling Machine

Number of Divisions.	Number of Holes in the Index Circle.	Number of Turns of the Crank.	Number of Divisions.	Number of Holes in the Index Circle.	Number of Turns of the Crank.
2	Any	20	35	49	$1\frac{7}{49}$
3	39	$13\frac{13}{39}$	36	27	$1\frac{3}{27}$
4	Any	10	37	37	$1\frac{3}{37}$
5	,,	8	38	19	$1\frac{1}{19}$
6	39	$6\frac{26}{39}$	39	39	$1\frac{1}{39}$
7	49	$5\frac{35}{49}$	40	Any	1
8	Any	5	41	41	$\frac{40}{41}$
9	27	$4\frac{12}{27}$	42	21	$\frac{20}{21}$
10	Any	4	43	43	$\frac{40}{43}$
11	33	$3\frac{21}{33}$	44	33	$\frac{30}{33}$
12	39	$3\frac{13}{39}$	45	27	$\frac{24}{27}$
13	39	$3\frac{3}{39}$	46	23	$\frac{20}{23}$
14	49	$2\frac{42}{49}$	47	47	$\frac{40}{47}$
15	39	$2\frac{26}{39}$	48	18	$\frac{15}{18}$
16	20	$2\frac{10}{20}$	49	49	$\frac{40}{49}$
17	17	$2\frac{6}{17}$	50	20	$\frac{16}{20}$
18	27	$2\frac{6}{27}$	52	39	$\frac{30}{39}$
19	19	$2\frac{2}{19}$	54	27	$\frac{20}{27}$
20	Any	2	55	33	$\frac{24}{33}$
21	21	$1\frac{19}{21}$	56	49	$\frac{35}{49}$
22	33	$1\frac{27}{33}$	58	29	$\frac{20}{29}$
23	23	$1\frac{17}{23}$	60	39	$\frac{26}{39}$
24	39	$1\frac{26}{39}$	62	31	$\frac{20}{31}$
25	20	$1\frac{12}{20}$	64	16	$\frac{10}{16}$
26	39	$1\frac{21}{39}$	65	39	$\frac{24}{39}$
27	27	$1\frac{13}{27}$	66	33	$\frac{20}{33}$
28	49	$1\frac{21}{49}$	68	17	$\frac{10}{17}$
29	29	$1\frac{11}{29}$	70	49	$\frac{28}{49}$
30	39	$1\frac{13}{39}$	72	27	$\frac{15}{27}$
31	31	$1\frac{9}{31}$	74	37	$\frac{20}{37}$
32	20	$1\frac{5}{20}$	75	15	$\frac{8}{15}$
33	33	$1\frac{7}{33}$	76	19	$\frac{10}{19}$
34	17	$1\frac{6}{17}$	78	39	$\frac{20}{39}$

Index Table for Use with the Dividing Head of Milling Machine—*continued.*

Number of Divisions.	Number of Holes in the Index Circle.	Number of Turns of the Crank.	Number of Divisions.	Number of Holes in the Index Circle.	Number of Turns of the Crank.
80	20	$\frac{10}{20}$	164	41	$\frac{10}{41}$
82	41	$\frac{20}{41}$	165	33	$\frac{8}{33}$
84	21	$\frac{10}{21}$	168	21	$\frac{5}{21}$
85	17	$\frac{8}{17}$	170	17	$\frac{4}{17}$
86	43	$\frac{20}{43}$	172	43	$\frac{10}{43}$
88	33	$\frac{15}{33}$	180	27	$\frac{6}{27}$
90	27	$\frac{12}{27}$	184	23	$\frac{5}{23}$
92	23	$\frac{10}{23}$	185	37	$\frac{8}{37}$
94	47	$\frac{20}{47}$	188	47	$\frac{10}{47}$
95	19	$\frac{8}{19}$	190	19	$\frac{4}{19}$
98	49	$\frac{20}{49}$	195	39	$\frac{8}{39}$
100	20	$\frac{8}{20}$	196	49	$\frac{10}{49}$
104	39	$\frac{15}{39}$	200	20	$\frac{4}{20}$
105	21	$\frac{8}{21}$	205	41	$\frac{8}{41}$
108	27	$\frac{10}{27}$	210	21	$\frac{4}{21}$
110	33	$\frac{12}{33}$	215	43	$\frac{8}{43}$
115	23	$\frac{8}{23}$	216	27	$\frac{5}{27}$
116	29	$\frac{10}{29}$	220	33	$\frac{6}{33}$
120	39	$\frac{13}{39}$	230	23	$\frac{4}{23}$
124	31	$\frac{10}{31}$	232	29	$\frac{5}{29}$
128	16	$\frac{5}{16}$	235	47	$\frac{8}{47}$
130	39	$\frac{12}{39}$	240	18	$\frac{3}{18}$
132	33	$\frac{10}{33}$	245	49	$\frac{8}{49}$
135	27	$\frac{8}{27}$	248	31	$\frac{5}{31}$
136	17	$\frac{5}{17}$	260	39	$\frac{6}{39}$
140	49	$\frac{14}{49}$	264	33	$\frac{5}{33}$
144	18	$\frac{5}{18}$	270	27	$\frac{4}{27}$
145	29	$\frac{8}{29}$	280	49	$\frac{7}{49}$
148	37	$\frac{10}{37}$	290	29	$\frac{4}{29}$
150	15	$\frac{4}{15}$	296	37	$\frac{5}{37}$
152	19	$\frac{5}{19}$	300	15	$\frac{2}{15}$
155	31	$\frac{8}{31}$	310	31	$\frac{4}{31}$
156	39	$\frac{10}{39}$	212	39	$\frac{5}{39}$
160	20	$\frac{5}{20}$	360	18	$\frac{2}{18}$

Differential Indexing.—A method of indexing known as compound indexing has been brought into use in order

to obtain divisions that are prime numbers, and which cannot be obtained by direct indexing. This method is complicated, as it necessitates the use of two circles. Messrs Brown & Sharpe introduced around 1900 a much simpler method of indexing than by compounding, the indexing being obtained in the same manner as in plain indexing, excepting that the spindle of the dividing head is geared to the index plate. Being geared together the movement of the dividing head spindle in relation to the index crank is positive. Thus a differential motion can be obtained that allows the indexing to be made with one circle of holes and the index crank turned in one direction.

Ordinarily, forty revolutions of the index crank are required to make one revolution of the spindle. Therefore, if the index plate is geared to the spindle, using one idler so as to rotate the index plate one turn in the same direction as the crank, and crankpin enters the same index plate hole, the result will be the spacing number 39, for the reason that while the crank has made 40 turns and the plate one turn in the same direction, the crank has passed a given point only 39 times. With this same gearing, and the addition of another idler, the motion of the index plate is in the opposite direction to that of the crank, and the plate gives one revolution while the crank has made 40, resulting in the spacing number 41.

Any divisions, including fractions not obtainable with the index plate, can therefore be made up with proper gearing, and the change wheels and index plates usually furnished provide for all divisions from 1 to 382.

Examples of Horizontal Milling

Fig. 362 shows an example of horizontal index milling, the illustration being the cutting of notches in the locking

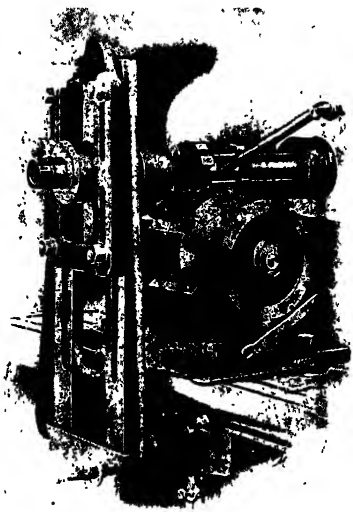


FIG. 362. -Index Milling.

rings of automatic screw machines. The rings are of tool steel, and are mounted in gangs in a special indexing fixture.

Two cutters are mounted upon the arbor of the machine, one being a stocking cutter and the second a formed finishing cutter of the same shape as the groove.

The table is moved transversely for finishing after the roughing cut has been taken. The ends of the arbor carrying the discs to be milled are supported by cylindrical

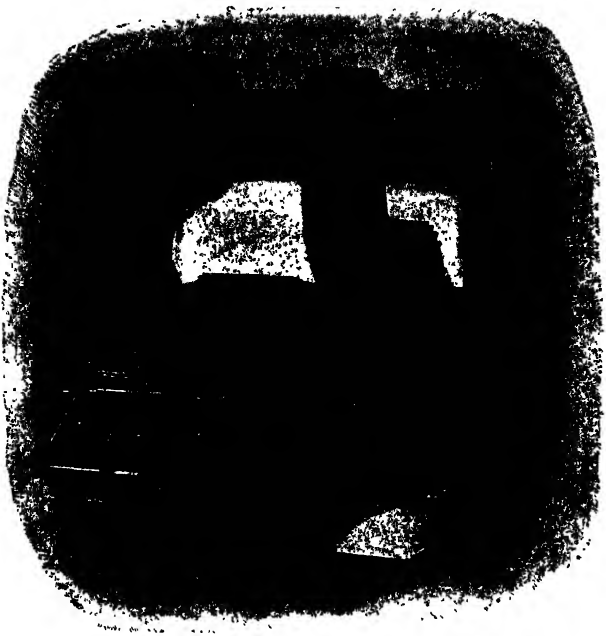


FIG. 363.—Gang Milling.

bearings, and not by centres, giving better support and enabling much heavier milling to be done.

The use of special fixtures is always justified where the work occurs in sufficient quantities.

Fig. 363 illustrates a gang of cutters milling the top and sides of a number of castings.

Fig. 364 shows a good example of broad milling with wide formed cutters. The work operated upon consists of conveyor links milled in gangs. This type of cutter can be sharpened without changing their form.

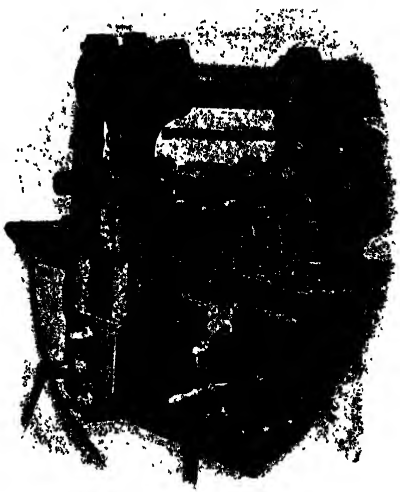


FIG. 364.—Form Milling.

Cutting Speeds and Feeds when Milling

With such a wide range of cutting materials, and metals used in engineering design, it is impossible to give here full information as to the most appropriate cutting speed and feed for each alloy. And the difficulty is increased

immensely when one takes into account the effects of heat treatment or cold working.

In each instance the chosen cutting speed should be based upon the horse power input of the machine, the feed, depth of cut, and number of teeth on the cutter. Hence the figures given in the table below are only tentative, and for fuller information one should consult a work dealing chiefly with this important phase of machine-shop technique.

APPROXIMATE CUTTING SPEEDS AND FEEDS FOR MILLING VARIOUS METALS WITH HIGH SPEED STEEL CUTTERS

Material	Cutting Speed for Roughing	Cutting Speed for Finishing	Feed per Rev. Roughing	Feed per Rev. Finishing.
	Ft per Min	Ft per Min		
Hard steel	20 to 30	25 to 50	0·135	0·03
Mild steel	30 ,, 65	50 ,, 80	0·156	0·03
Cast iron	20 ,, 40	35 ,, 60	0·155	0·02
Brass	70 ,, 90	90 ,, 130	0·16	0·04
Tool steel	15 ,, 25	20 ,, 40	0·14	0·02
Wrought iron	35 ,, 70	80 ,, 100	0·159	0·03
Aluminum	250 ,, 300	250 ,, 400	—	

Knowing the cutting speed in f.p.m. one may readily compute the speed of the machine spindle in r.p.m. :—

$$\text{Spindle speed r.p.m.} = \frac{12 \times \text{Cutting speed in f.p.m.}}{3.14 \times \text{Dia. of cutter in inches.}}$$

Machine Set-up.—The set-up of every milling machine should be such as to give the maximum rigidity to the cutter and workpiece. Hence the arbor for cylindrical mills should be as large as possible in diameter, whilst the

cutter should be placed as near to the nose of the spindle as circumstances permit, and the end bracket should be placed so that the deflection of the cutter under the heaviest operating conditions is negligible. With small taper shank end mills and profile cutters great care should be taken to ensure that the reactions of the cutting force cannot pull the cutter out of the spindle nose.

Cutting Lubricants.—The remarks given on page 255 as to the value of a suitable cutting lubricant also applies when milling, hence further comments are unnecessary.

Milling Cutters

Successful milling can only be accomplished by the use of durable and correctly made cutters, which are capable of doing a considerable amount of work without the need of regrinding. The smaller cutters are generally made from the solid metal, the larger sizes are of the built-up type having the cutting edges of high speed steel, Stellite, or cemented carbide let into a holder of, say, carbon steel.

The solid form of cutter is a disc of High Speed Steel made with the front faces of the teeth cut to give the required top rake. The requisite clearance angle is given, the land at the top of tooth being left about .03 in. wide. The tooth angle is approximately 50°.

Plain cylindrical mills having helical teeth are made up to, say, 5 in. in diameter, but the length seldom exceeds 3 in.

The number of teeth in a cutter varies with the diameter. If the teeth of a cutter are too finely spaced there is a great tendency for the chips to clog in the cutter flutes, and thereby reduce the cutting efficiency. Tests made with cutters of similar diameter, having teeth of different pitch, have been made, and it is found that by reducing the number of teeth 50 per cent., the power required was reduced something like 30 per cent. It has been clearly proved that for roughing work a coarse tooth cutter gives a saving in power, is more durable, and allows of a much heavier feed per tooth.

The following table shows the approximate number of teeth given to milling cutters :—

Diameter, Inches.	No. of Teeth.	Diameter, Inches.	No. of Teeth.
½	4	2½	8
¾	4	3	8
1	6	3½	10
1¼	6	4	12
1½	6	4½	12
1¾	8	5	14
2	8	5½	16

Types of Cutters

Milling cutters are made in various forms to perform certain classes of work, and they may be classified chiefly as slab mills, facing cutters, end mills, angular, and form cutters. Figs. 365 to 371 illustrate several types of cutters

in general use. The most simple type of cutter is perhaps the fly cutter. This consists of one cutter made from square or oblong section steel, with the cutting edge formed to the shape desired. As these cutters have only one cutting edge, they are easy to make, and will be found to cut very

FIG. 365.—Slab Mills.

accurately. They are produced with very little expense, and may therefore be used where only one job of a particular shape is required.

Cylindrical Cutter or Slab Mill.—Fig. 365 illustrates the ordinary type of cutter used for producing a flat surface on work of a general character. With these cutters one side of the job is finished at each operation.

Formed Cutters.—Figs. 366 and 367 show a simple

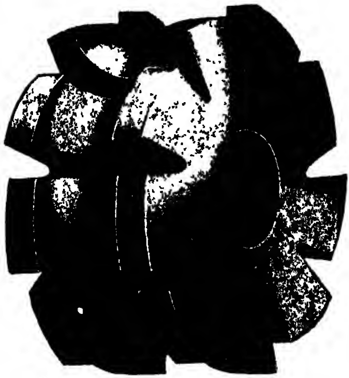


FIG. 366.—Concave Cutter.

FIG. 367.—Convex Cutter.

type of formed cutter, one being for concave and the other for convex work. Formed cutters are made in innumerable

varieties of shapes, and may be intended for such simple operations as fluting taps or twist-drills, or for the most intricate reproduction work. It is quite common to use

FIG 368. -Side and Face or Slotting Cutter.

various types of cutters in gangs, placing one or more formed cutters with side mills on the arbor at one time, and using them collectively.

Side Milling.—For side milling or keyway cutting the mill shown in Fig. 368 is used. This type of cutter can be worked in pairs by mounting them on the arbor with a distance piece in between. By setting them up in that

manner they can be used for milling two sides of a piece of work at one operation, as in the forming of the head of a bolt, and are then called straddle mills.

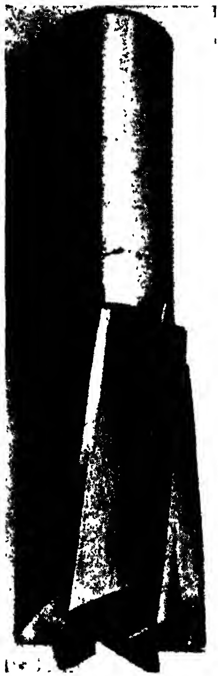


FIG. 369.—Parallel Shank Spiral End Mill.

End Milling.—Fig. 369 shows an end mill. This is a combination of the face and side milling cutter. It is used for such work as recessing, slotting, and facing.

Gear Cutters.—For cutting the teeth of spur and chain wheels a cutter similar to that shown in Fig. 370 is used.

FIG. 370.—Gear Cutter.

Tee-Slot Milling.—For cutting tee-shaped slots the cutter shown in Fig. 371 can be used after the first portion

FIG. 371.—Tee-Slot Cutter.

has been machined. Dovetail slots, and slots of any particular shape, can be cut in a similar manner.

To list examples of every type of milling cutter would take up too much space, but sufficient have been given to show that a wide range of work can be carried out in an efficient and accurate manner by means of the milling machine and well-designed cutters.

Broaching

While not a milling operation in the strict sense of the term, a broaching operation is very often necessary in conjunction with milling in the finishing of the bore of gears, for instance, which have to fit on a splined shaft. A splined shaft fitting in a splined bore is shown in Fig. 372, and it will be readily observed that the splines on the end of the shaft may be cut on the lines shown in Fig. 362, a comparatively simple operation. The splined bore could be cut by a slotting operation, but for rapid production work the broach is usually employed.

As will be seen from Fig. 373, a broach can be formed to cut any shape of hole, and it is quite often used for sizing a circular bore; it is one recognised method of cutting small internal gears, and it may be used for cutting spiral grooves in preference to a threading operation. In the tool-room or on small work this operation is often quite well done by pushing relatively short broaches through the work by means of a hand or hydraulically operated press. In production a special broaching machine is used, and the broach, which is usually much longer, is pulled through the work by means of a screw forming part of the machine. Push broaches must necessarily be quite short to prevent excessive deflection; consequently, it is often necessary to force several broaches through the work. The longer broaches

which are pulled through in regular broaching machines commonly finish parts in one passage, although a series

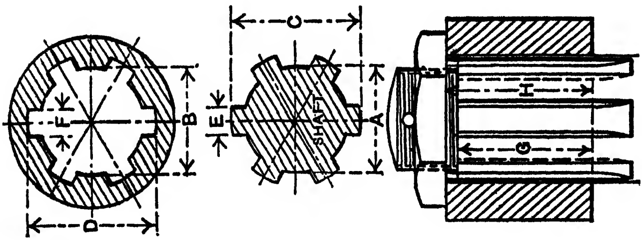


Fig. 372.—Example of Broaching.

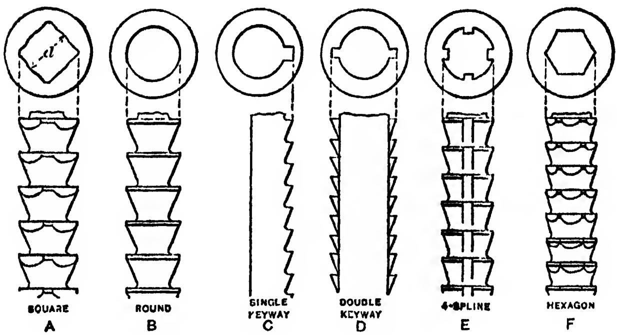


Fig. 373.—Forms of Broaches.

of two or more broaches are often used for long holes, or when considerable stock must be removed. The number of broaches ordinarily used varies from one to four.

Comparatively short broaches are sometimes used because they are easier to make, are not warped excessively in hardening, and are easier to handle. Two or more parts can frequently be finished simultaneously on a regular broaching machine, the pieces being placed one against the other, in tandem.

In the case of the familiar square hole, as shown at the left of Fig. 373, it is not usually necessary to make a clean square cut, which accounts for the somewhat irregular shape shown. Prior to the broaching operation a hole is drilled slightly larger in diameter than the square width. The first tooth on the broach is rounded considerably and cuts a long circular chip, and the following teeth form the square corners by removing successive chips until the square is finished. The first tooth has the widest cut, the chip width decreasing towards the finishing end of the broach; hence, if this hole is finished with a single broach, it is advisable to vary the sizes of the teeth so that the depth of cut gradually increases as the width decreases. It is good practice to nick some of the wide teeth in order to break up the chips, as a broad curved chip does not bend or curl easily. In case two or more broaches are required, the first broach of the set might have a uniform variation in the radii of different teeth, but the depth of cut should be less than for the following broaches which remove comparatively narrow chips from the corners of the square. Several end teeth, especially on the last broach of a set, are made to the finished size. This feature, which is common to broaches in general, aids the broach

in retaining its size and tends to produce a more accurately finished hole.

An illustration of a horizontal broaching machine by Kendall & Gent of Manchester is shown in Fig. 374. The design follows the modern tendency in that the machine has an individual motor, thus doing away with the need for line shafting.

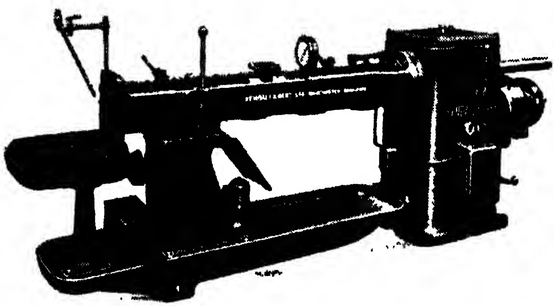


FIG. 374.—Broaching Machine.
(By courtesy of Messrs Kendall & Gent Ltd., Manchester.)

CHAPTER XVIII

GEARS AND GEAR CUTTING

OWING to the great usefulness of spur, helical, bevel, and worm gearing, and their practically noiseless running when properly designed and correctly cut, a large demand has been created for this form of power transmission, especially in the motor car industry.

Very few tooth wheels are now cast, and in cases where that method of production is still used the teeth patterns are formed in a special gear-cutting machine. The great demand for gears with machine-cut teeth has led to the introduction of many forms of gear-cutting machines, but for small-scale production the milling machine may be used for all types within the capacity of the plant available. It is, of course, understood that when the teeth are helical a universal miller is required.

Description of Various Gears

Spur Gears are toothed gears which give motion to or receive motion from a parallel shaft.

Racks are a series of teeth on a straight line and can be considered as spur gear of infinite radii.

Internal Gears have teeth parallel to their axes and convergent to their centres to permit pinion wheels working on their inner circumference.

Worm Gearing usually has the two shafts lying at right angles to each other (see Fig. 427, page 505).

Bevel Gears have the pitch line at various degrees from the centre line, their axes generally being at right angles to each other.

Mitre Gears have an equal number of teeth and the pitch cone makes an angle of 45° from the centre line; their axes always lie at 90°.

Helical and Spiral Gears have teeth or threads at any desired angle to suit the object of the drive. The axes of the mating gears may be parallel, at an angle less than 90° or at an angle over 90°.

Pitch Lines are the rolling circumferences of two or more gears acting on each other.

Form and Proportions of Wheel Teeth

When teeth of gears form part of the body of a wheel they are termed teeth, but when separately fitted they are termed cogs.

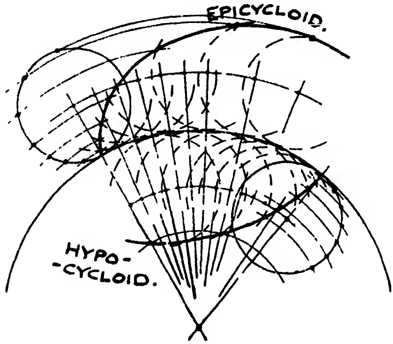
The cycloidal form of teeth has some advantages, but the demand for machine-cut teeth has caused its replacement to a great extent by the involute.

Cycloidal teeth were generally used for cast gear; the tooth contour being that developed by the pattern maker.

The involute is a single curve tooth, and can be generated by a cutter, which possesses only a point or a plain straight line. It has many advantages, the chief being that involute gears will work well together when the centres are slightly varied.

Method of Drawing the Curves.—Epicycloid and hypocycloid curves may be drawn by rolling a templet of the size of the pitch circle inside and outside templets of the size of the pitch circle. A pencil, held in contact with the rolling templet, describes the required curve. Fig. 375

shows an epicycloid generated by a $\frac{7}{8}$-in. circle rolling outside a 3-in. diameter circle, and Fig. 376 a hypocycloid obtained by a $\frac{7}{8}$-in. circle rolling inside a 3-in. circle.



FIGS. 375 and 376.—Epicycloid and Hypocycloid Curves.

A cycloid is generated by a point in the circumference of a circle which rolls on a straight line. Fig. 377 shows part of the cycloid generated on a $1\frac{1}{2}$-in. circle. It will

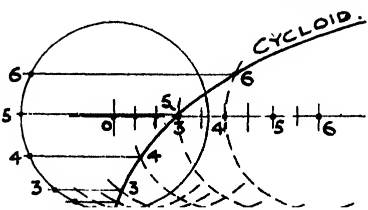


FIG. 377.—Cycloid Curve.

be noticed that, as the circle rolls, points 3, 4, 5, and 6 will describe circular arcs, the complete path from any one point producing the cycloid.

Involute Curves.—An involute curve may be obtained by winding a cord round a circular disc, first making a loop in the outer end of the cord, and then laying the disc

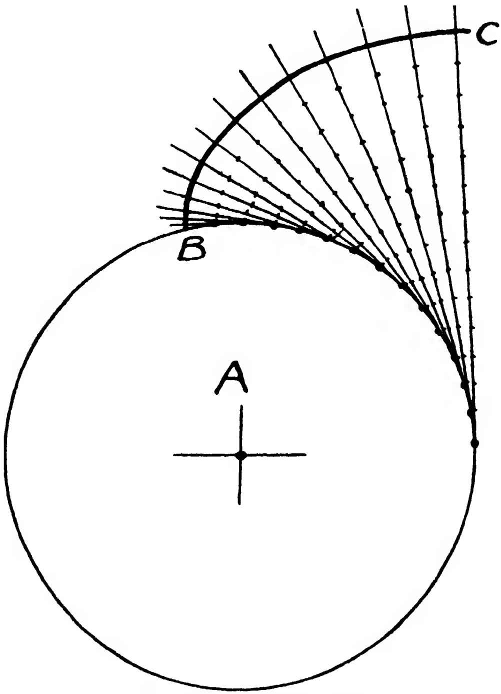


Fig. 378.—Involute Curve.

flat on a sheet of paper. With the pencil in the loop, unwind the string, keeping it drawn tight, and let the point of the pencil trace a curve, which will be an involute. The development of an involute curve will be seen in Fig. 378.

Proportions of Cast Teeth

A common and usual type of wheel tooth form is shown in Fig. 379. In working, the faces of the teeth of one wheel come into contact with the flanks of the teeth of the other wheel. The proportions are :—

Let pitch	- - - -	= P
Then thickness of tooth	- -	= .48 P
,, width of space	- -	= .52 P
,, height of tooth	- -	= .7 P
,, height above pitch line	-	= .3 P
,, height inside pitch line	-	= .4 P

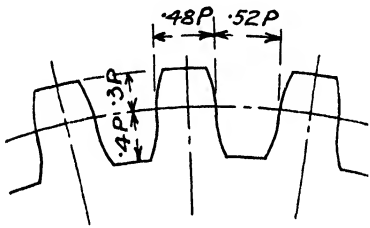


FIG. 379.—Wheel Teeth Proportions.

To compute the pitch of a wheel: Divide the circumference at pitch line by the number of teeth.

To find the diameter of the wheel: Multiply the number of teeth by the pitch, and divide the product by 3.1416.

To compute the number of teeth in a wheel: Divide the circumference by the pitch.

Involute Teeth.—All involute tooth wheels which have the same pitch, and the same obliquity of the line of contact, work well together; and because of the many practical advantages of this shape of tooth it is now generally adopted.

The Sizing and Cutting of Spur Gears

In considering spur gears the most important measurement is pitch diameter. The pitch diameter is intermediate between the top and bottom of the tooth, and is represented by an imaginary line; its position will be seen in Fig. 380.

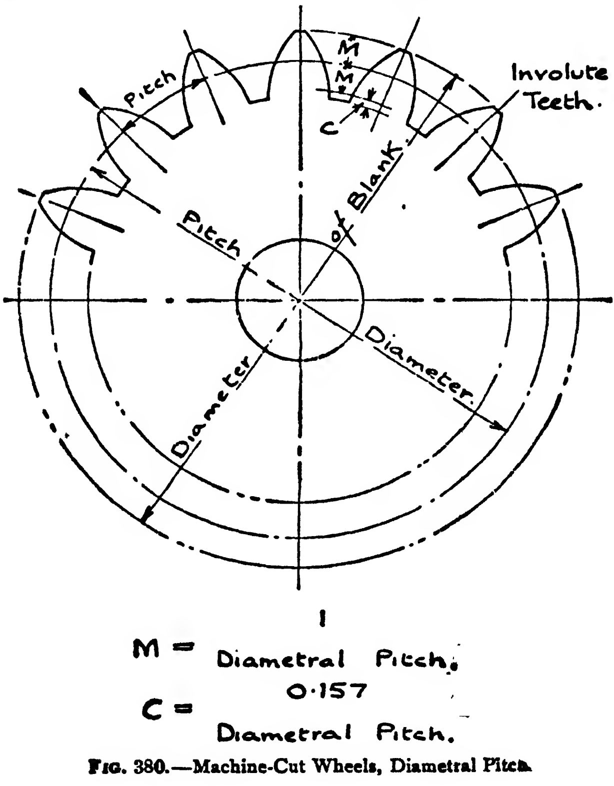


FIG. 380.—Machine-Cut Wheels, Diametral Pitch.

Pitch.—The pitch of spur wheels can be taken in two different ways—circular pitch and diametral pitch. The method most frequently adopted is by *diametral pitch.* This does not represent actual measurement, but really expresses a ratio. By diametral pitch is meant the number of teeth per inch of pitch diameter, and when a wheel is spoken of as being 12 diametral pitch it simply means that the wheel has 12 teeth for each inch of pitch diameter; thus, if the wheel had 42 teeth, the pitch diameter would be $42 \div 12 = 3.5$ in.

The other method of considering the pitch of a wheel is by *circular pitch*; this represents the distance between the centres of two teeth measured on the pitch circle.

Diameter, when applied to gears, is always understood to mean pitch diameter. Diametral pitch is the number of teeth to each inch of pitch diameter.

Example.—If a gear has 40 teeth, and the pitch diameter is 4 in., there are 10 teeth to an inch of pitch diameter, and the diametral pitch is 10, or in other words, the gear is 10 diametral pitch.

Circular Pitch is the distance from the centre of one tooth to the centre of the next, measured along the pitch line.

Example.—If the distance from the centre of one tooth to the centre of the next, measured along the pitch line, is $\frac{1}{2}$ in., the gear is $\frac{1}{2}$ in. circular pitch.

To find Number of Teeth.—When the pitch diameter and diametral pitch are given, multiply the pitch diameter by the diametral pitch.

Example.—If the diameter of the pitch circle is 10 in., and the diametral pitch is 4, multiply 10 by 4, and the product 40 will be the number of teeth in the gear.

CIRCULAR PITCH

Circular Pitch is the Distance from the Centre of One Tooth to the Centre of the Next Tooth, Measured along the Pitch Line.

To Get	Having	Rule.	Formula.
The Circular Pitch.	The Diametral Pitch.	Divide 3.1416 by the Diametral Pitch	$P' = \frac{3.1416}{P}$
The Circular Pitch.	The Pitch Diameter and the Number of Teeth	Divide Pitch Diameter by the product of .3183 and Number of Teeth	$P' = \frac{D'}{.3183\ N}$
The Circular Pitch.	The Outside Diameter and the Number of Teeth	Divide Outside Diameter by the product of .3183 and Number of Teeth plus 2	$P' = \frac{D}{.3183\ N+2}$
Pitch Diameter.	The Number of Teeth and the Circular Pitch	The continued product of the Number of Teeth, the Circular Pitch and .3183	$D' = NP'\ .3183$
Pitch Diameter.	The Number of Teeth and the Outside Diameter	Divide the product of Number of Teeth and Outside Diameter by Number of Teeth plus 2 . . .	$D' = \frac{ND}{N+2}$
Pitch Diameter.	The Outside Diameter and the Circular Pitch	Subtract from the Outside Diameter the product of the Circular Pitch and .6366	$D' = D - (P'\ .6366)$
Pitch Diameter.	Addendum and the Number of Teeth.	Multiply the Number of Teeth by the Addendum . . .	$D' = N\,s$
Outside Diameter.	The Number of Teeth and the Circular Pitch . . .	The continued product of the Number of Teeth plus 2, the Circular Pitch and .3183 . .	$D = (N+2)P'.3183$
Outside Diameter.	The Pitch Diameter and the Circular Pitch	Add to the Pitch Diameter the product of the Circular Pitch and .6366	$D = D' + (P'\ .6366)$
Outside Diameter.	The Number of Teeth and the Addendum	Multiply Addendum by Number of Teeth plus 2	$D = s\ (N+2)$
Number of Teeth.	The Pitch Diameter and the Circular Pitch	Divide the product of Pitch Diameter and 3.1416 by the Circular Pitch	$N = \frac{D'\ 3.1416}{P'}$
Thickness of Tooth.	The Circular Pitch.	One-half the Circular Pitch . .	$t = \frac{P'}{2}$
Addendum.	The Circular Pitch.	Multiply the Circular Pitch by .3183, or $s = \frac{D'}{N}$	$s = P'\ .3183$
Root.	The Circular Pitch.	Multiply the Circular Pitch by .3683	$s + f = P'\ .3683$
Working Depth.	The Circular Pitch.	Multiply the Circular Pitch by .6366	$D'' = P'\ .6366$
Whole Depth.	The Circular Pitch.	Multiply the Circular Pitch by .6866	$D'' = P'\ .6866$
Clearance.	The Circular Pitch.	Multiply the Circular Pitch by .05	$f = P'\ .05$
Clearance.	Thickness of Tooth.	One-tenth the Thickness of Tooth at Pitch Line	$f = \frac{t}{10}$

DIAMETRAL PITCH

Diametral Pitch is the Number of Teeth to Each Inch of the Pitch Diameter.

To Get	Having	Rule.	Formula.
The Diametral Pitch.	The Circular Pitch.	Divide 3.1416 by the Circular Pitch	$P = \frac{3.1416}{P'}$
The Diametral Pitch.	The Pitch Diameter and the Number of Teeth	Divide Number of Teeth by Pitch Diameter	$P = \frac{N}{D'}$
The Diametral Pitch.	The Outside Diameter and the Number of Teeth . . .	Divide Number of Teeth plus 2 by Outside Diameter	$P = \frac{N+2}{D}$
Pitch Diameter.	The Number of Teeth and the Diametral Pitch . . .	Divide Number of Teeth by the Diametral Pitch . . .	$D' = \frac{N}{P}$
Pitch Diameter.	The Number of Teeth and Outside Diameter	Divide the product of Outside Diameter and Number of Teeth by Number of Teeth plus 2 .	$D' = \frac{DN}{N+2}$
Pitch Diameter.	The Outside Diameter and the Diametral Pitch .	Subtract from the Outside Diameter the quotient of 2 divided by the Diametral Pitch	$D' = D - \frac{2}{P}$
Pitch Diameter.	Addendum and the Number of Teeth.	Multiply Addendum by the Number of Teeth	$D' = sN$
Outside Diameter.	The Number of Teeth and the Diametral Pitch	Divide Number of Teeth plus 2 by the Diametral Pitch	$D = \frac{N+2}{P}$
Outside Diameter.	The Pitch Diameter and the Diametral Pitch	Add to the Pitch Diameter the quotient of 2 divided by the Diametral Pitch	$D = D' + \frac{2}{P}$
Outside Diameter.	The Pitch Diameter and the Number of Teeth	Divide the Number of Teeth plus 2 by the quotient of Number of Teeth and by the Pitch Diameter.	$D = \frac{N+2}{\frac{N}{D'}}$
Outside Diameter.	The Number of Teeth and Addendum .	Multiply the Number of Teeth plus 2 by Addendum . .	$D = (N+2)s$
Number of Teeth.	The Pitch Diameter and the Diametral Pitch	Multiply Pitch Diameter by the Diametral Pitch	$N = D'P$
Number of Teeth.	The Outside Diameter and the Diametral Pitch	Multiply Outside Diameter by the Diametral Pitch and subtract 2.	$N = DP - 2$
Thickness of Tooth.	The Diametral Pitch.	Divide 1.5708 by the Diametral Pitch	$t = \frac{1.5708}{P}$
Addendum.	The Diametral Pitch.	Divide 1 by the Diametral Pitch, or $s = \frac{D'}{N}$	$s = \frac{1}{P}$
Root.	The Diametral Pitch.	Divide 1.157 by the Diametral Pitch	$s + f = \frac{1.157}{P}$
Working Depth.	The Diametral Pitch.	Divide 2 by the Diametral Pitch.	$D'' = \frac{2}{P}$
Whole Depth.	The Diametral Pitch.	Divide 2.157 by the Diametral Pitch	$D'' + f = \frac{2.157}{P}$
Clearance.	The Diametral Pitch.	Divide .157 by the Diametral Pitch	$f = \frac{.157}{P}$
Clearance.	Thickness of Tooth.	Divide Thickness of Tooth at pitch line by 10	$f = \frac{t}{10}$

Diametral Pitch.—When circular pitch is given, divide 3.1416 by the circular pitch.

Example.—If the circular pitch is 2 in., divide 3.1416 by 2, and the quotient, 1.5708, is the diametral pitch.

Diametral Pitch.—When number of teeth and outside diameter are given, add 2 to the number of teeth, and divide by the outside diameter.

Example.—If the number of teeth is 40, the diameter of the blank 10½ in., add 2 to the number of teeth, making 42, divide by 10½; the quotient, 4, is the diametral pitch.

Circular Pitch Required.—Diametral pitch given. Divide 3.1416 by the diametral pitch.

Example.—If the diametral pitch is 4, divide 3.1416 by 4, and the quotient, .7854, is the circular pitch.

Number of Teeth Required.—Outside diameter and diametral pitch given. Multiply the outside diameter by the diametral pitch and subtract 2.

Example.—If the whole diameter is 10½ in., and the diametral pitch is 4, multiply 10½ by 4, and the product, 42 less 2, or 40, is the number of teeth.

Outside Diameter or size of gear blank required. Number of teeth and diametral pitch given. Add 2 to the number of teeth and divide by the diametral pitch.

Example.—If the number of teeth is 40, and the diametral pitch 4, add 2 to 40, making 42, and divide by 4; the quotient, 10½, is the whole diameter of the gear or blank.

Thickness of Tooth at Pitch Line.—Divide the circular pitch by 2, or 1.57 by the diametral pitch.

Example.—If the circular pitch is 1.047 in., or the diametral pitch 3, divide 1.047 by 2, or 1.57 by 3, and the quotient, .523 in., is the thickness of tooth.

Whole Depth of Tooth Required.—Divide 2.157 by the diametral pitch.

Example.—If the diametral pitch of a wheel is 6, the whole depth is 2.157 divided by 6, which equals .3595.

Distance Between Centres of Two Gears Required.—Add number of teeth together, and divide one-half of the sum by the diametral pitch.

Example.—If two gears have 50 and 30 teeth respectively and are 5 pitch, add 50 to 30, making 80, divide by 2, and then divide the quotient, 40, by the diametral pitch, 5, and the result, 8 in., is the centre distance.

TABLE SHOWING DEPTH OF A TOOTH TO THE PITCH LINE AND THE WHOLE DEPTH OF A TOOTH

Having the Diametral Pitch

Diametral Pitch.	Depth to Pitch Line.	Total Depth of Tooth.	Diametral Pitch.	Depth to Pitch Line.	Total Depth of Tooth.
1	1·0000	2·1571	10	0·1000	0·2157
1¼	0·8000	1·7257	11	0·0909	0·1961
1½	0·6666	1·4381	12	0·0833	0·1798
1¾	0·5714	1·2326	13	0·0769	0·1659
2	0·5000	1·0785	14	0·0714	0·1541
2¼	0·4444	0·9587	15	0·0666	0·1438
2½	0·4000	0 8628	16	0·0625	0·1348
2¾	0·3636	0·7844	17	0·0588	0·1269
3	0·3333	0·7190	18	0·0555	0·1198
3½	0·2857	0·6163	19	0·0526	0·1135
4	0·2500	0·5393	20	0·0500	0·1079
5	0·2000	0·4314	21	0·0476	0·1026
6	0·1666	0·3595	22	0·0454	0·0980
7	0·1429	0·3081	23	0·0434	0·0936
8	0·1250	0·2696	24	0·0417	0·0898
9	0·1111	0·2397			

Cutters for Involute Gears

The sets of cutters for involute teeth on the Brown & Sharpe system number eight for each pitch, but they are

often supplemented by seven half numbers for cutting an intermediate number of teeth :—

No. 1 will cut wheels from 135 teeth to a rack.
" 2 " " 55 " 134 teeth.
" 3 " " 35 " 54 "
" 4 " " 26 " 34 "
" 5 " " 21 " 25 "
" 6 " " 17 " 20 "
" 7 " " 14 " 14 "
" 8 " " 12 " 12 "

The half numbers are :—

No. $1\frac{1}{2}$ will cut 80 to 134 teeth.
" $2\frac{1}{2}$ " 42 " 54 "
" $3\frac{1}{2}$ " 30 " 34 "
" $4\frac{1}{2}$ " 23 " 25 "
" $5\frac{1}{2}$ " 19 " 20 "
" $6\frac{1}{2}$ " 15 " 16 "
" $7\frac{1}{2}$ " 13 " ... "

Average Speeds for Gear Cutters

Diametral Pitch of Cutter.	Diameter of Cutter.	Turns per Min. for Cast Iron.	Turns per Min. for Wrought Iron and Steel.	Feed to One Turn of Cutter in Cast Iron.	Feed to One Turn of Cutter in Wrought Iron and Steel.	Feed per Min. in Cast Iron.	Feed per Min. in Wrought Iron and Steel.
	In.			In.	In.	In.	In.
2	5	24	18	0·025	0·011	0·60	0·20
$2\frac{1}{2}$	$4\frac{1}{4}$	30	24	0·028	0·013	0·84	0·31
3	$3\frac{11}{16}$	36	28	0·031	0·015	1·12	0·42
4	$3\frac{3}{8}$	42	32	0·034	0·017	1·43	0·54
5	$3\frac{1}{16}$	50	40	0·037	0·019	1·85	0·76
6	$2\frac{11}{16}$	75	55	0·030	0·016	2·25	0·88
7	$2\frac{9}{16}$	85	65	0·032	0·018	2·72	1·17
8	$2\frac{1}{2}$	95	75	0·034	0·020	3·23	1·50
10	$2\frac{1}{8}$	125	90	0·026	0·014	3·25	1·26
12	2	135	100	0·027	0·017	3·64	1·70
20	$1\frac{7}{8}$	145	115	0·029	0·021	4·20	2·41
32	$1\frac{3}{4}$	160	135	0·031	0·025	4·96	3·37

For brass, the speeds may be twice those for cast iron.

High-speed cutters may be run at from two to three times these speeds.

Cycloidal Form of Teeth

Cutters for the cycloidal form of teeth are also made so that any gear of one pitch will mesh into any other gear or into a rack of the same pitch, but twenty-four cutters are required for each pitch. In order that gears with this form of teeth shall run well together, they must be cut accurately to the required depth; otherwise the pitch circles will not be tangent to each other. To secure a proper depth of tooth, the cutters are made with a shoulder which determines the exact depth that the tooth should be cut. Thus, if care is taken when turning the blanks to obtain the correct outside diameter of the gear, no measurements need be taken when cutting the teeth. The twenty-four cutters are adapted to cut from a pinion of twelve teeth to a rack, and are designated by letters A, B, C, etc. The number of teeth and the pitch for which the cutter is adapted is marked on each. A list of the twenty-four cutters with the number of teeth they are intended to cut is given in the following table:—

CUTTERS FOR CYCLOIDAL GEAR TEETH

Cutter	A	cuts	12	teeth.	Cutter	M	cuts	27	to	29	teeth.
,,	B	,,	13	,,	,,	N	,,	30	,,	33	,,
,,	C	,,	14	,,	,,	O	,,	34	,,	37	,,
,,	D	,,	15	,,	,,	P	,,	38	,,	42	,,
,,	E	,,	16	,,	,,	Q	,,	43	,,	49	,,
,,	F	,,	17	,,	,,	R	,,	50	,,	59	,,
,,	G	,,	18	,,	,,	S	,,	60	,,	74	,,
,,	H	,,	19	,,	,,	T	,,	75	,,	99	,,
,,	I	,,	20	,,	,,	U	,,	100	,,	149	,,
,,	J	,,	21 to 22	,,	,,	V	,,	150	,,	249	,,
,,	K	,,	23 ,, 24	,,	,,	W	,,	250 or more.			
,,	L	,,	25 ,, 26	,,	,,	X	,,	Rack.			

Metric Pitch

The following formula can be used for determining the dimensions of gears by metric pitch.

The module is the pitch diameter in millimetres divided by the number of teeth in the wheel. In Fig. 381, let :—

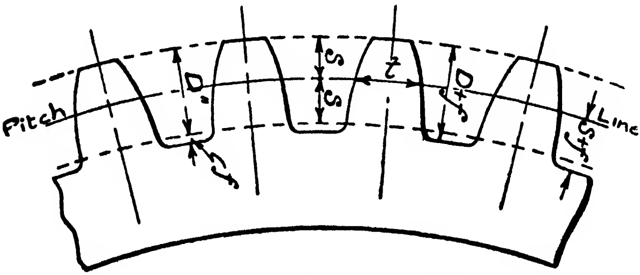


FIG. 381.—Metric Pitch Formula.

M = Module.
D′ = The pitch diameter of the gear.
D = The whole diameter of the gear.
N = Number of teeth in the gear.
D″ = Working depth of gear.
t = Thickness of tooth at pitch line.
f = Amount added to depth for clearance.

Then,

$$M=\frac{D'}{N} \text{ or } \frac{D}{N+2}.$$

$$D'=NM.$$

$$D=(N+2)M.$$

$$N=\frac{D'}{M} \text{ or } \frac{D}{M}-2.$$

$$D''=2M.$$

$$t=M\times 1{\cdot}5708.$$

$$f=\frac{M\times 1{\cdot}5708}{10}=\cdot 157\,M.$$

MODULES OF PITCHES COMMONLY USED

Module.	Circular Pitch.	Total Height of Tooth.	Corresponding English Diametrical Pitch.
Mm.	Mm.	Mm.	
·5	1·57	1·08	50·800
1·0	3·14	2·16	25·400
1·25	3·93	2·7	20·320
1·5	4·71	3·23	16·933
1·75	5·5	3·77	14·514
2·0	6·28	4·31	12·700
2·25	7·07	4·85	11·288
2·5	7·86	5·4	10·160
2·75	8·63	5·93	9·236
3·0	9·42	6·47	8·466
3·25	10·2	7·0	7·81
3·5	11·0	7·55	7·257
3·75	11·77	8·09	6·773
4·0	12·57	8·63	6·350
4·25	13·35	9·17	5·708
4·5	14·14	9·71	5·644
4·75	14·92	10·24	5·347
5·0	15·71	10·78	5·080
5·25	16·49	11·33	4·838
5·5	17·28	11·86	4·618
6·0	18·86	12·94	4·233
6·5	20·41	14·02	3·907
7·0	22·0	15·1	3·628
8·0	25·14	17·26	3·175
9·0	28·27	19·41	2·822
10·0	31·41	21·57	2·540
11·0	34·56	23·72	2·309
12·0	37·7	25·88	2·117

Milling Spur Wheel Teeth

The method of setting up a spur wheel blank is shown in Fig. 382. The blank is mounted on a mandrel, held between centres, and the dividing head is set to index the number of teeth required. The centre of the cutter must be exactly in line with the headstock and tailstock centres.

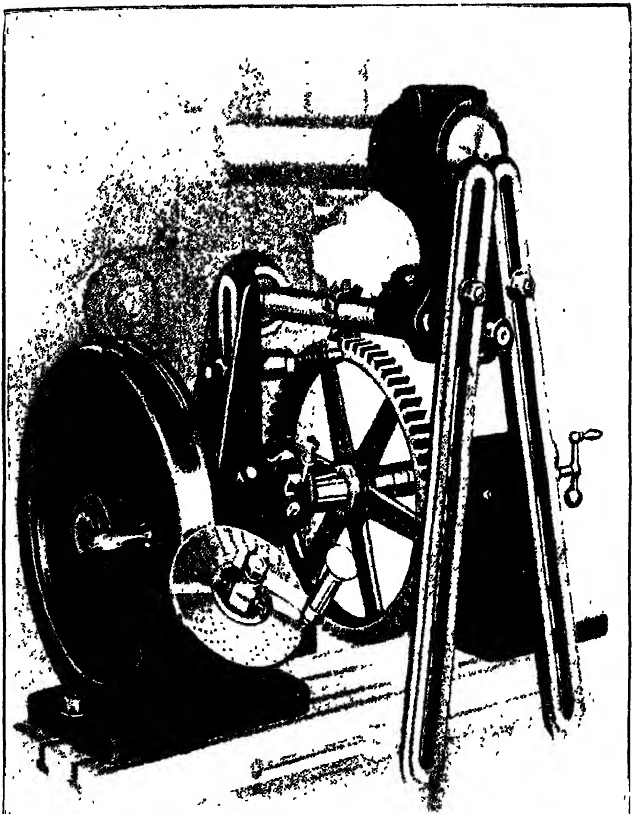


FIG. 382.—Method of Setting Wheel Blank.

Internal Spur Gearing

Internal spur gears have teeth formed on an interior pitch circle, as shown in Fig. 383. With a pinion working in an internal gear, both wheels revolve in the same

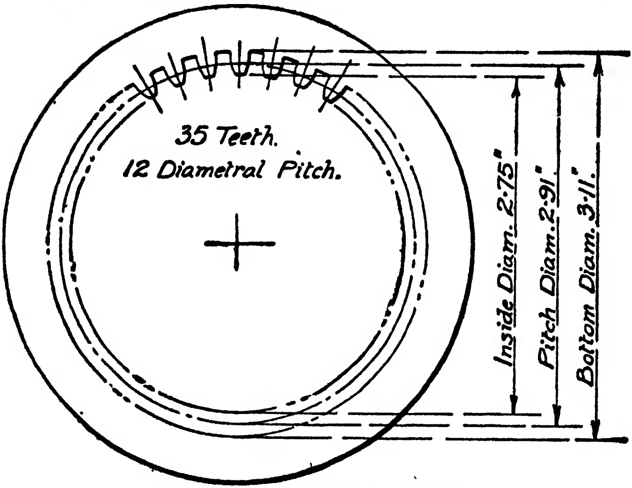


FIG. 383.—Internal Spur Gearing.

direction, whereas with an external pinion and wheel the direction of rotation is reversed. The following rules apply to internal spur gears:—

Rules for Internal Gears

To find inside diameter, subtract 2 from the number of teeth and divide the remainder by the diametral pitch.

To find inside diameter, subtract 2 from the number of teeth, multiply the remainder by the circular pitch, and divide the product by 3.1416.

To find the pitch diameter add twice the addendum to the inside diameter.

To find inside diameter subtract twice the addendum from the pitch diameter.

To find the bottom diameter add twice the dedendum and clearance to the pitch diameter.

Gears of this description possess the following advantages: For a given pitch and number of teeth, the centre distances for internal gears are considerably smaller than those of corresponding pitch external gears. Internal gears have their teeth protected to a large extent. The curvature of the pitch circles are in the same direction for pinion and wheel, and therefore the teeth mesh more freely and gradually than ordinary spur gears.

Cutting Internal Spur Gears

Internal spur gears can be cut in the milling machine by making use of a special attachment made for that particular purpose. The arrangement is shown in Fig. 384. It consists of two cheek plates constructed to hold a train of four wheels; the front pair of wheels allow the cutter to be placed between them, and the other wheels gear the cutter to the spur gear, which is keyed on to the machine arbor. The arrangement is bolted on to the overhanging arm support.

The blank to be cut is held on the face plate, or in the chuck of the dividing head.

Chordal Pitch

Chordal pitch is the length of a straight line or chord connecting the centres of two adjacent teeth at the pitch line. Chordal pitch is never used in connection with

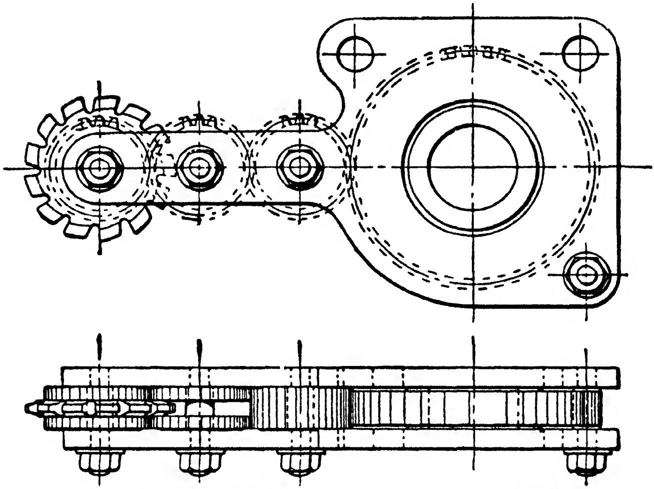


FIG. 384.—Cutting Arrangement for Internal Gears.

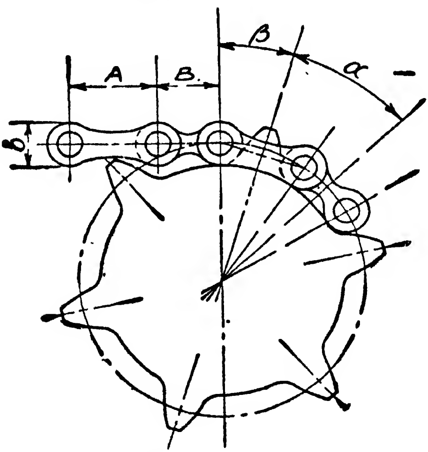


FIG. 385.—Chordal Pitch.

machine-cut spur wheels, but it is used to express pitch of machine-cut sprocket wheels for chains.

The following formula can be used for calculating diameters of sprocket wheels for block centre chains (Fig. 385):—

FORMULA

N = Number of teeth.
b = Diameter of round part of chain block.
B = Centre to centre of holes in chain block.
A = Centre to centre of holes in side links.

$$\alpha = \frac{180^\circ}{N}. \qquad \text{Tan } \beta = \frac{\text{Sin } \alpha}{\frac{B}{A} + \text{Cos } \alpha}.$$

$$\text{Pitch diameter} = \frac{A}{\text{Sin } \beta}.$$

Outside diameter = Pitch diameter + b.
Bottom diameter = Pitch diameter − b.

The following formula can be used for calculating diameters of sprocket wheels for roller chains (Fig. 386):—

FORMULA

N = Number of teeth in sprocket.
P = Pitch of chain.
D = Diameter of chain.

$$\alpha = \frac{180^\circ}{N}. \qquad \text{Pitch diameter} = \frac{P}{\text{Sin } \alpha}.$$

Outside diameter = Pitch diameter + D.
Bottom diameter = Pitch diameter − D.

Bevel Gears

Bevel gears are normally used to connect shafts whose axes would meet if they were extended. When bevel gears are of equal size and have the same number of teeth, and their centre lines intersect, they are termed mitre gears.

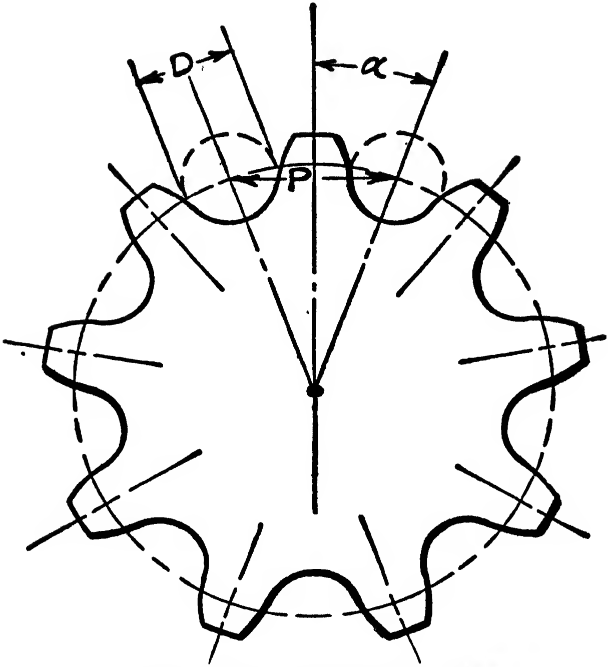


FIG. 386.—Sprocket Wheels for Roller Chains.

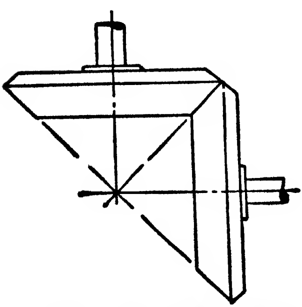


FIG. 387.—Possible Arrangement of Bevel Gears.

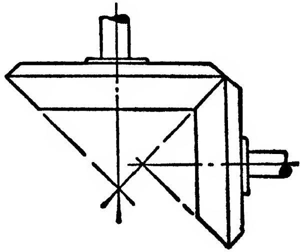


FIG. 388.—Arrangement for Hypoid Bevel Gears.

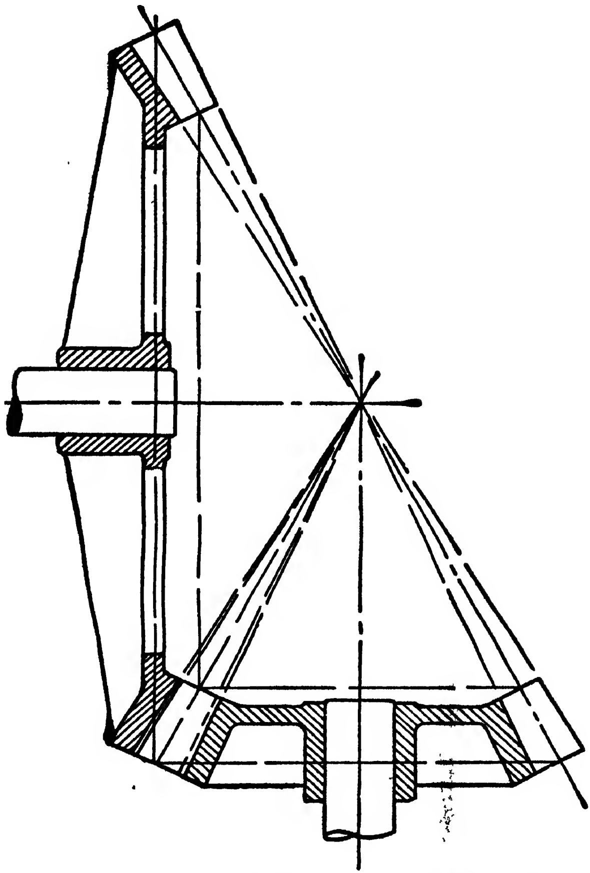


FIG. 389.—Two to One Bevel Gear and Pinion in Section.

Bevel gears are virtually cones, the teeth being formed about the frustums of cones whose apexes are at the same point where the axes of the shafts meet.

An arrangement of bevel wheels is shown in Fig. 387, where two wheels are of equal size. In Fig. 388 is shown

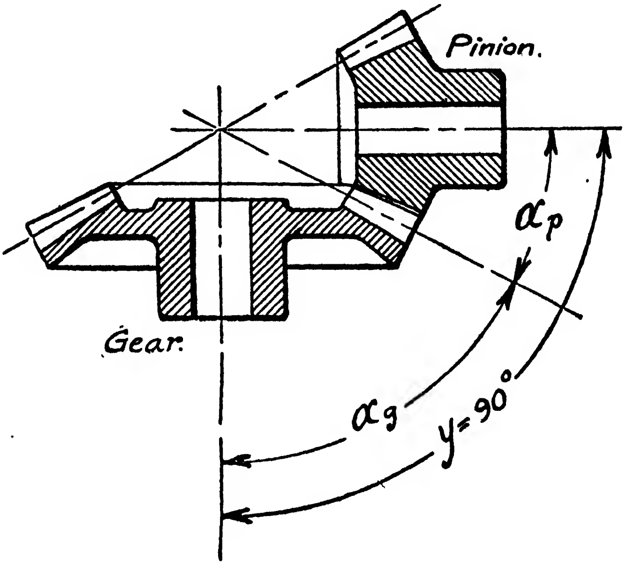


FIG. 390.—Formula for Bevel Gearing.

an arrangement for the hypoid bevel gear set. A two to one gear ratio is shown in section in Fig. 389.

Formulas for Bevel Gearing

The following formula will be found suitable for bevel gears with shafts at right angles. The notation used refers to Figs. 390 and 391. Certain modifications are

sometimes made. Thus, when cutting bevel wheel teeth with a formed bevel cutter on a milling machine, the cutting angle is determined by subtracting the addendum angle from the pitch cone angle, instead of subtracting the dedendum angle, with the result that the clearance at the bottom of the tooth is made uniform instead of tapering.

When using a generating machine, and a pinion having

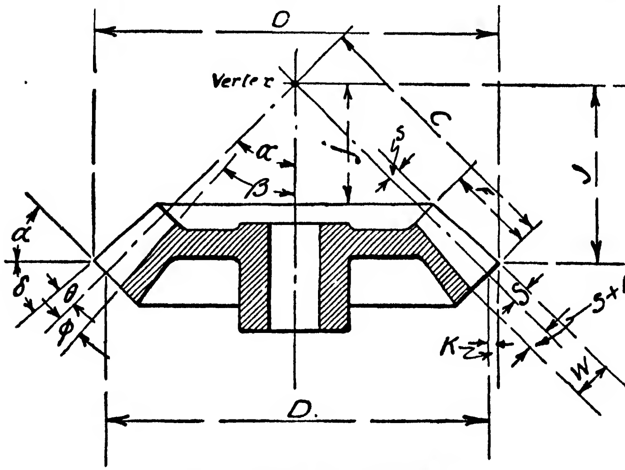


FIG. 391.—Formula for Bevel Gearing.

a small number of teeth is being cut for a wheel having a large number of teeth, the addendum on the pinion is made larger, and the dedendum correspondingly smaller. This is done to avoid interference and consequent undercut on the flanks of pinions having a small number of teeth. Where pinions are made of bronze and gears of steel, the teeth of the pinion are often made larger and the teeth of the gear smaller in order to equalise the strength.

Rules and Formulas

Shafts at Right Angles

To Find	Rule.	Formula.
Pitch cone angle (or edge angle) of pinion	Divide the number of teeth in the pinion by the number of teeth in the gear to get the tangent	$\text{Tan } a_p = \frac{N_p}{N_g}$
Pitch cone angle (or edge angle) of gear	Divide the number of teeth in the gear by the number of teeth in the pinion to get the tangent	$\text{Tan } a_g = \frac{N_g}{N_p}$
Proof of calculations for pitch cone angles	The sum of the pitch cone angles of the pinion and gear equals 90°	$a_p + a_g = 90°$
Pitch diameter	Divide the number of teeth by the diametral pitch; or multiply the number of teeth by the circular pitch and divide by 3·1416	$D = \frac{N}{P} = \frac{NP'}{\pi}$
/Addendum	Divide 1·0 by the diametral pitch; or multiply the circular pitch by 0·318	$S = \frac{1{\cdot}0}{P} = 0{\cdot}318P'$
Dedendum	Divide 1·157 by the diametral pitch; or multiply the circular pitch by 0·368	$S + A = \frac{1{\cdot}157}{P} = 0{\cdot}368P'$
Whole depth of tooth space	Divide 2·157 by the diametral pitch; or multiply the circular pitch by 0·687	$W = \quad = 0{\cdot}687P'$
Thickness of tooth at pitch line	Divide 1·571 by the diametral pitch; or divide the circular pitch by 2	$= \frac{1{\cdot}571}{P} = \frac{P'}{2}$
Pitch cone radius	Divide the pitch diameter by twice the sine of the pitch cone angle	$= \frac{-}{2 \times \text{Sin } a}$

Rules and Formulas—*continued*

Shafts at Right Angles

To Find	Rule.	Formula.
Addendum at small end of tooth	Subtract the width of face from the pitch cone radius, divide the remainder by the pitch cone radius, and multiply by the addendum	$s = S \times \frac{C-F}{C}$
Thickness of tooth at pitch line at small end	Subtract the width of face from the pitch cone radius, divide the remainder by the pitch cone radius, and multiply by the thickness of the tooth at the pitch line	$t = T \times \frac{C-F}{C}$
Addendum angle	Divide the addendum by the pitch cone radius to get the tangent	Tan $\theta =$
Dedendum angle	Divide the dedendum by the pitch cone radius to get the tangent	Tan $\phi = \frac{S+A}{C}$
Face angle	Subtract the sum of the pitch cone and addendum angles from 90°	$\delta = 90° - (\alpha + \theta)$
Cutting angle	Subtract the dedendum angle from the pitch cone angle	$\zeta = \alpha - \phi$
Angular addendum	Multiply the addendum by the cosine of the pitch cone angle	$K = S \times \text{Cos } \alpha$
Outside diameter	Add twice the angular addendum to the pitch diameter	$O = D + 2K$
Apex distance	Multiply one-half the outside diameter by the tangent of the face angle	$J = \frac{O}{2} \times \text{Tan } \delta$
Apex distance at small end of tooth	Subtract the width of face from the pitch cone radius, divide the remainder by the pitch cone radius, and multiply by the apex distance	$j = J \times C - F$
Number of teeth in equivalent spur gear	Divide the number of teeth by the cosine of the pitch cone angle	$N' = \frac{N}{\text{Cos } \alpha}$

FORMULAS FOR MITRE GEARS

To Find	Rule.	Formula.
Pitch cone angle	Pitch cone angle equals 45°	$\alpha = 45°$
Pitch cone radius	Multiply the pitch diameter by 0·707	$C = 0{\cdot}707D$
Face angle	Subtract the addendum angle from 45°	$\delta = 45° - \theta$
Cutting angle	Subtract the dedendum angle from 45°	$\zeta = 45° - \phi$
Angular addendum	Multiply the addendum by 0·707	$K = 0{\cdot}707S$
Number of teeth in equivalent spur gear	Multiply the number of teeth by 1·41	$N' = 1{\cdot}41N$

Milling Cutters for Bevel Gears

Milling cutters for mitre and bevel gears are, in the Brown & Sharpe system, made in sets of eight. They differ from spur gear cutters, being 0.005 of an inch thinner than the tooth space at the small end, allowing for the tooth length to be not longer than one-third the distance from the large diameter of the teeth to the apexes of the cones. Wheels to be cut having longer tooth faces require special cutters.

Bevel wheel teeth change their pitch from the small to the large end, and it is on account of this alteration in size that it is impossible to cut gears whose tooth curves are theoretically correct with rotary cutters having fixed curves. The cutter that must be employed should make

the correct form of tooth at the large end, and in doing so it will leave the curve at the small end too straight; the gear will then require to be finished correctly by hand.

Size of Cutter

To find the correct size of a cutter, measure the back cone radius A in Fig. 392 for the gear, and B for the

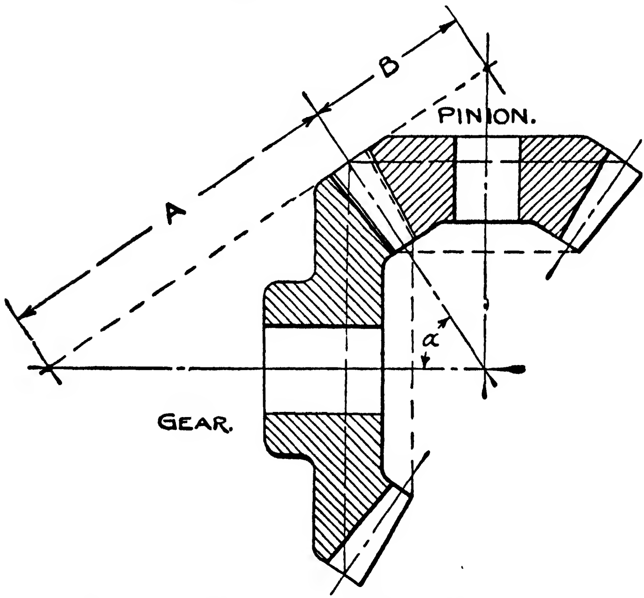


FIG. 392.—Measurements for obtaining required Cutter.

pinion. This is equal to the radius of a spur gear, the number of teeth in which would determine the cutter to use. Thus, twice A times the diametral pitch equals the

number of teeth for which the cutter should be selected for the gear, and which would be taken from the set of bevel gear cutters.

Example.—Let the back cone radius A equal 4 in. and the diametral pitch 8. Then twice 4 equals 8, and 8 times 8 equals 64, from which it can be seen that the cutter to be used is shape and size No. 2, because 64 is between 55 and 134, the range covered by a No. 2 cutter.

The following formula will give the number of teeth for which the cutter should be selected :—

Let Na = Number of teeth in gear.

$$\text{Then } \tan a = \frac{N}{\text{Cos } a}.$$

Let Nb = Number of teeth in pinion.

Let a = Centre angle of gear.

$$\text{Number of teeth for pinion} = \frac{Nb}{\text{Sine } a}.$$

$$\text{Number of teeth to select cutter for gear} = \frac{Na}{\text{Cos } a}.$$

Position of Blank and Cutter

As it is impossible to use a cutter thicker than the width of the space between the teeth at the small end, it is necessary to set the blank out of centre and also rotate it in order to make the space the correct width at the large end.

The amount the cutter has to be set out of the centre can be found with the aid of the following table and formula :—

Formula.-

$$\text{Set-over } \frac{Tc}{2} - \frac{\text{Factors from table}}{P}.$$

P = Diametral pitch of gear to be cut.

Tc = Thickness of cutter at pitch line.

Table for Obtaining Set-Over for Cutting Bevels

Ratio of Apex Distance to Width of Face $= \frac{\text{Apex}}{\text{Face}}$.

No. of Cutter.	$\frac{3}{1}$	$\frac{3\frac{1}{4}}{1}$	$\frac{3\frac{1}{2}}{1}$	$\frac{3\frac{3}{4}}{1}$	$\frac{4}{1}$	$\frac{4\frac{1}{4}}{1}$	$\frac{4\frac{1}{2}}{1}$	$\frac{4\frac{3}{4}}{1}$	$\frac{5}{1}$	$\frac{5\frac{1}{2}}{1}$	$\frac{6}{1}$	$\frac{7}{1}$	$\frac{8}{1}$
1	·254	·254	·255	·256	·257	·257	·257	·258	·258	·259	·260	·262	·264
2	·266	·268	·271	·272	·273	·274	·274	·275	·277	·279	·280	·283	·284
3	·266	·268	·271	·273	·275	·278	·280	·282	·283	·286	·287	·290	·292
4	·275	·280	·285	·287	·291	·293	·296	·298	·298	·302	·305	·308	·311
5	·280	·285	·290	·293	·295	·296	·298	·300	·302	·307	·309	·313	·315
6	·311	·318	·323	·328	·330	·334	·337	·340	·343	·348	·352	·356	·362
7	·289	·298	·308	·316	·324	·329	·334	·338	·343	·350	·360	·370	·376
8	·275	·286	·296	·309	·319	·331	·338	·344	·352	·361	·368	·380	·386

Two cuts have to be taken with the cutter through each tooth space, the gear blank being first on one side of the centre and then on the other. The gear blank is also rotated to make the spaces the right width at the large end of the teeth.

Use of Table

The following example will show the use of the table:—

A bevel gear of 24 teeth, 6 pitch, 30° pitch cone angle, and $1\frac{1}{4}$-in. face. Find the offset.

From the dimensions it will be seen that a No. 4 cutter is required, and that the apex distance is 4 in.

The ratio of the apex distance to the length of face is 4 to 1.25, or about $3\frac{1}{4}$ to 1. The factor in the table for this ratio with a No. 4 cutter is 0.280. The thickness of the cutter at the pitch line must be found by measurement. To do this, find the depth of space below pitch line by dividing 1.157 by the diametral pitch; this will be $1.157 \div 6 = 0.1928$. The thickness of the cutter will be found to be 0.1745. This dimension will vary with different cutters, and also in the same cutter as it is ground away, since formed bevel cutters are provided with side relief. Substituting the values in the formula, the following result is obtained:—

Offset $= \dfrac{0.1745}{2} - \dfrac{0.280}{6} = 0.0406$ in., which is the required amount of offset.

Setting the Blank

The blank is mounted on a suitable size mandrel held in the chuck, or on a special arbor placed in the spindle of the dividing head. The head is then swung round until the root line of the tooth is parallel with the top of the table.

The proper cutter is then selected and brought central with the work and spindle. The spiral head is now set to index the number of teeth required.

The next operation is to mark the full depth of the cut on the blank on both small and large ends. This can be done with a small scratch gauge specially made for the purpose.

Two or three centre cuts can now be taken to the marked lines, and the cutter can be set out of centre and the amount of offset decided upon by moving the saddle and reading the amount on the dial indicator. Next rotate the gear in the opposite direction from that in which the table is moved off the centre, as shown by the arrows in Fig. 393, until the side of the cutter nearest the centre line will cut the entire surfaces of the approaching sides of the teeth. After a cut has been taken which agrees with the setting, move the table the same distance on the opposite side of the centre and rotate the gear in the opposite direction in the same manner as before, only to cut on the opposite side. When this cut has been taken, gauge the thickness of the tooth at both ends with the tooth caliper or a thickness gauge. If the thickness at the large end is too great when the small end is correct, the amount to set the table out of centre must be increased; or if the small end is too thick when the large end is correct, the amount the table is set out of centre is too much.

Adjustments are made until the tooth thickness is correct, and when the correct distance to set the cutter out of centre is found, the teeth can be finished without making the central cut at all, by cutting round the blank, first on one side of the centre and then on the other.

It will be found that the teeth are of correct shape on the large ends, but the sides of the small ends will be too straight, and therefore it will be necessary to file the faces

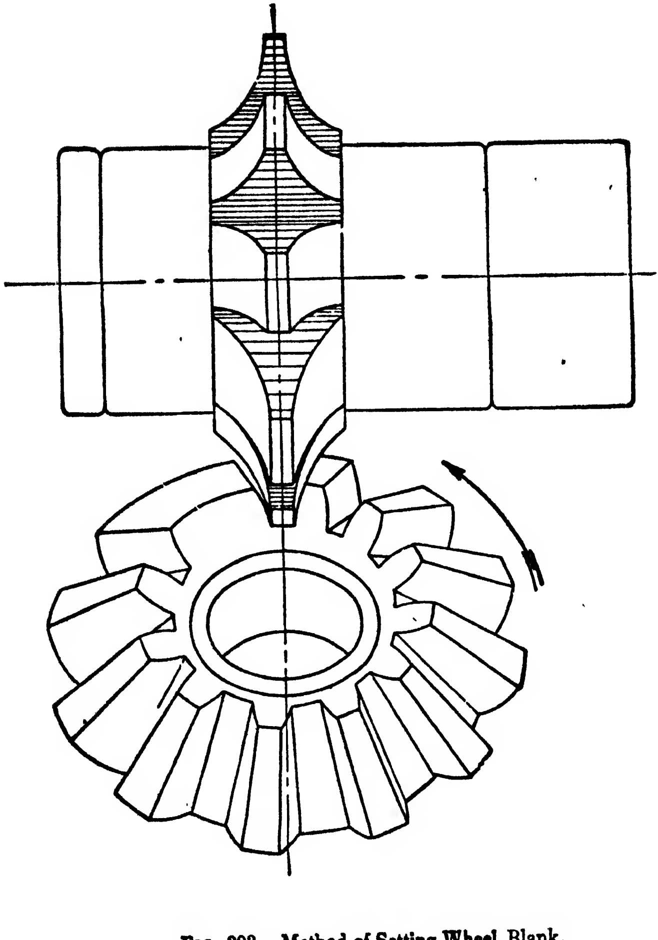


FIG. 393.—Method of Setting Wheel Blank.

of the teeth at the small end to make them rounded from a little above the pitch line, as shown in Fig. 394 at c, c.

The general set-up is shown in Fig. 395, the gear blank being mounted on an arbor inserted in the dividing head spindle while the latter is set to the cutting angle as indicated. Although a formed cutter is used, it will be

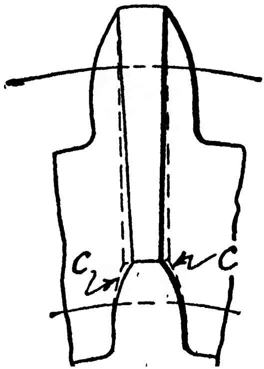


FIG. 394.—Correcting a Bevel Gear Tooth Shape.

obvious that it is necessary to take at least two cuts through each tooth gap to obtain approximately the correct form, while the blank is rotated proportionately to obtain the proper tooth thickness at the large and small ends. The cutting angle α at which the dividing head spindle is set is equal to the pitch cone angle β minus the addendum angle θ of the tooth. Under ordinary circumstances the cutting angle for a bevel gear is the pitch angle less the

dedendum angle, but the rule given may be preferable when using a milling cutter as it gives a uniform clearance

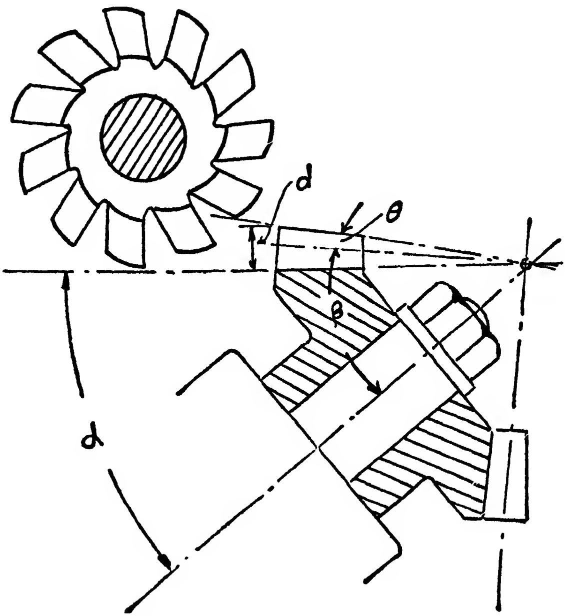


FIG. 395.—Cutting Bevel Wheel.

at the bottom of the tooth spaces and a somewhat closer approximation to the mathematically correct shape.

The foregoing is essentially suitable for small-scale production or general jobbing work. However, gashing

the teeth by means of milling cutters is a usual method of roughing-out the blanks of bevel gears, and is one to be recommended for any large-scale production as it relieves much of the work on the costly finishing machines.

Helical Gears

The helices commonly cut in milling machines are gears, milling cutters, drills, and counterbores, and with the aid of special attachments, worms.

Teeth of gears can be considered as a portion of a worm or screw thread. The path formed by the thread, or, as it is sometimes called, the helix, will be seen in Fig. 396. Here A B represents the circumference of the work, and A C the lead of the thread; therefore B C will be the angle formed by the thread.

The helix angle of a thread can be found graphically by drawing a right-angled triangle, two sides of which are formed by the circumference of the work and the lead. The angle can then be read off by means of a protractor.

Helix Angle

Another method for determining the angle of the helix is: First obtain the natural tangent of the angle by dividing the circumference of the work by the lead of the helix, and when the tangent of the angle is known, the corresponding angle in degrees and minutes can be found from a table of tangents.

In formula this would be :-

Let C = Circumference in inches.
" L = Lead in inches.
" T = Tangent.

Then, $T = \frac{C}{L}$ and $L = \frac{C}{T}$.

Example.—If the pitch diameter is $3\frac{1}{4}$ in., and the lead of the helix 24 in., find the angle.

$C = 3\frac{1}{4}\pi = 10{\cdot}21.$
$T = 10{\cdot}21 \div 24 = {\cdot}425.$

From a table of tangents .425 gives an angle of 23' 1'.

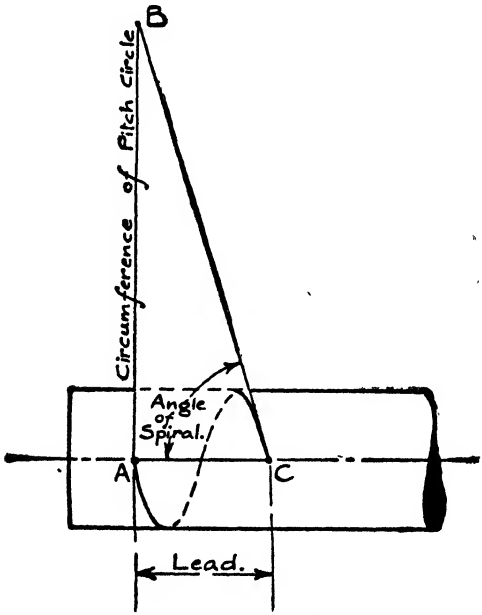


FIG. 396.—Helix of Screw Thread.

Helical Milling

The distance the thread or helix advances in one revolution is called the lead, and in order to give the necessary rotation to the work and obtain the given lead, the universal spiral head is brought into use.

The feed screw of the table of the milling machine has generally four threads per inch, that is, $\frac{1}{4}$-in. pitch. The dividing head is usually geared by means of a worm and worm wheel, so that forty turns of the worm are required to make one complete turn of the dividing head spindle, and therefore if a train of change wheels are used which give a ratio of 1 to 1, then the dividing head spindle will move a complete turn when the table has travelled a distance of 10 in., and the work would have a lead of 10 in.

The names given to the change wheels according to their position when in use are: Gear on worm, second stud wheel, first stud wheel, and gear on screw. The wheel on the table screw and the first stud wheel are drivers, and the wheel on the worm and the second stud wheel are driven. The wheels are shown in position in Figs. 397 and 398; in the latter case an idler is inserted for cutting left-hand leads.

By making use of the various combinations of wheels—the ratio of the longitudinal movement of the table to the spiral movement of the work—it is possible to obtain all the common leads required. The gears usually supplied with universal milling machines are—24 (2), 28, 32, 40, 44, 48, 56, 64, 72, 86, and 100.

Calculations for Change Gears

Calculations necessary to find the required change wheels to give a desired lead are practically the same as those for finding lathe change gears for screw cutting. In lathe work the ratio of the driving and the driven wheels

is the ratio between the number of threads to be cut per inch and the number of threads per inch on the lead

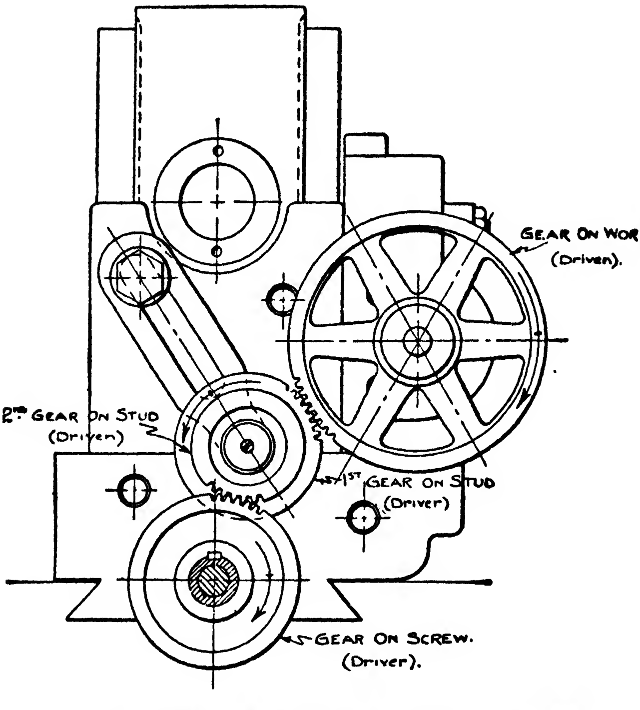


FIG. 397.—Arrangement of Wheels for Right-Hand Thread.

screw. On the milling machine the ratio of the driving and driven wheels is the ratio of the lead of the spiral to be cut to the lead of the machine table; or, the compound ratio of the driven to the driving wheels equals the

ratio of the lead of the required helix to the lead of the machine table.

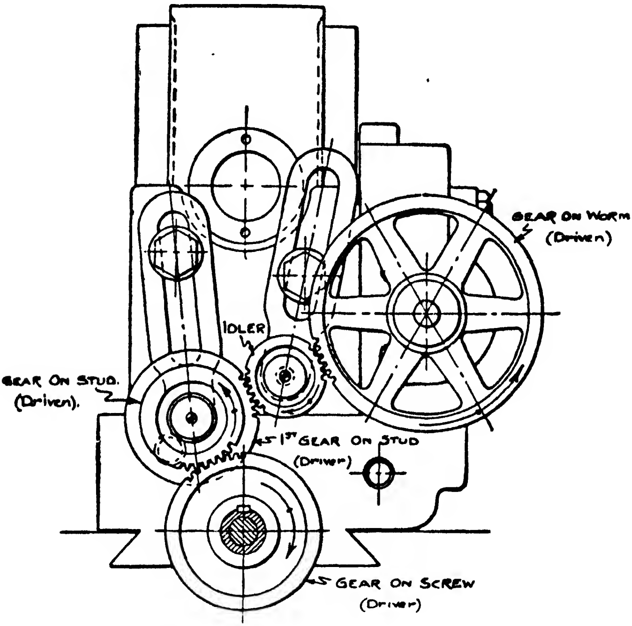


FIG. 398.—Arrangement of Wheels for Left-Hand Thread.

This can be expressed as:—

$$\frac{\text{Lead of required spiral}}{\text{Lead of machine table}} = \frac{\text{Driven gears}}{\text{Driving gears}}.$$

And if the lead of the machine is 10 in., then

$$\frac{\text{Product of driven gears}}{\text{Product of driving gears}} = \frac{\text{Lead of required spiral}}{10}.$$

Or, ten times the product of the driven wheels, divided by the product of the drivers, will give the lead of the resulting helix.

Ratio

If the required helix has a lead of 14 in. the ratio will be as 14 is to 10; or, dividing the lead required by 10, the quotient 1.4 will be the ratio to 1.

If the required helix has a lead of 36 in., the ratio will be as 36 is to 10, or as 3.6 is to 1.

Examples of Change Gears

Example.—Find the necessary gears to cut a helix having a lead of 27 in.

The ratio is as 27 is to 10, and can be expressed as a fraction, thus $\frac{27}{10}$; this fraction can be broken into factors giving $\frac{3}{2} \times \frac{9}{5}$. Taking each of these fractions separately and multiplying the numerators and denominators by 16 and 8 respectively, we get $\frac{3 \times 16}{2 \times 16} = \frac{48}{32}$ and $\frac{9 \times 8}{5 \times 8} = \frac{72}{40}$.

Then 32 and 40 are driving gears, and 48 and 72 driven gears.

Example.—Find the necessary gears to cut a helix having 1.5 in. lead.

The ratio is as 1.5 is to 10, or as a fraction, $\frac{1.5}{10}$. Breaking the denominator only into factors gives $\frac{1.5}{5 \times 2}$. Multiplying the numerator and the 5 by 20 will give $\frac{1.5 \times 20}{100 \times 2}$. Multiplying the 20 and 2 by 2 will give $\frac{1.5 \times 40}{100 \times 4}$, and multiplying the 1.5 and 4 by 16 will give $\frac{24 \times 40}{100 \times 64}$.

Then gear on screw, 100; first stud wheel, 64; second stud wheel, 40; and gear on worm, 24.

Proof of Change Gears

To ascertain the lead that will be cut by any set of change gears, divide ten times the product of the driven gears by the product of the drivers, and the quotient will be the lead of the resulting helix.

Example.—Find the lead that will be cut with the following train of wheels: Gear on worm, 56; first stud wheel, 32; second stud wheel, 40; gear on screw, 100.

Then 56 and 40 are driven wheels, 100 and 32 drivers; therefore

$$\text{Lead being cut} = \frac{56 \times 40 \times 10}{100 \times 32} = 7 \text{ in.}$$

The rule for finding the lead that can be cut with any set of change wheels is very useful, as it enables the operator to calculate the lead that can be cut by any gears already in position.

It should be remembered that while it is possible to place either of the drivers on the table screw, or either of the driven on the worm shaft, it is not possible to substitute a driver for a driven.

Rules and Formulas for Helical Gears

The following rules and formulas are suitable for helical gear calculations. The notation refers to Figs. 399 and 400, and the calculation should be taken in the order given.

To Find	Rule.	Formula.
Relation between shaft and tooth angles	The sum of the tooth angles of a pair of mating helical gears is equal to the shaft angle	$\gamma = \alpha_a + \alpha_b$
Pitch diameter	Divide the number of teeth by the product of the normal pitch and the cosine of the tooth angle	$D = \frac{N}{P_n \cos \alpha}$
Centre distance	Add together the pitch diameters of the two gears and divide by 2	$C = \frac{D_a + D_b}{2}$
Checking calculations in (2) and (3)	To prove the calculations for pitch diameters and centre distance, multiply the number of teeth in the first gear by the tangent of the tooth angle of that gear, and add the number of teeth in the second gear to the product; the sum should equal twice the product of the centre distance multiplied by the normal diametral pitch, multiplied by the sine of the tooth angle of the first gear	$N_b + (N_a \times \text{Tan } \alpha_a) = 2CP_n \times \text{Sine } \alpha_a$
No. of teeth for which to select cutter	Divide the number of teeth in the gear by the cube of the cosine of the tooth angle	$N' = \frac{N}{(\cos \alpha)^3}$
Lead of tooth helix	Multiply the pitch diameter by 3·1416 times the cotangent of the tooth angle	$L = \pi D \times \text{Cot } \alpha$
Addendum	Divide 1 by the normal diametral pitch	$S = \frac{1}{P_n}$
Whole depth of tooth	Divide 2·157 by the normal diametral pitch	$W = \frac{2{\cdot}157}{P_n}$
Normal tooth thickness at pitch line	Divide 1·571 by the normal diametral pitch	$T_n = 1{\cdot}571$
Outside diameter	Add twice the addendum to the pitch diameter	$O = D + 2S$

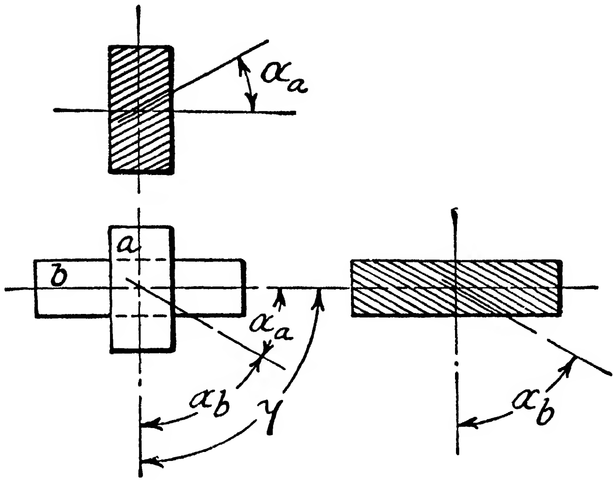


FIG. 399.—Formula for Helical Gears.

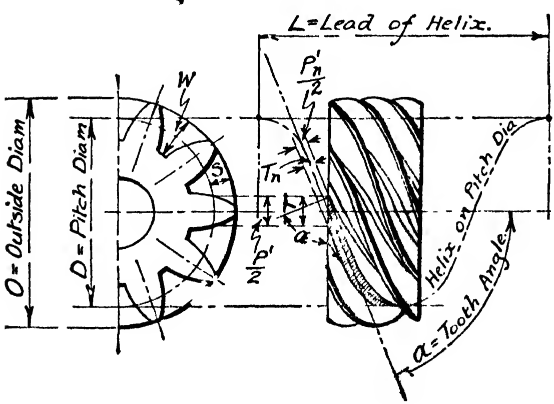


FIG. 400.—Formula for Helical Gears.

Examples

12 Pitch Helical Gear Parallel Shafts

Ratio 1 *to* 1

C_a = Approximate centre distance = 1·4 in.
P_n = Normal pitch = 12.
N = Teeth in both gears = 15.
a = Angle of helix = 15°.

$$D = \text{Pitch diameter} = \frac{N}{P_n \cos a} = \frac{15}{12 \times \cdot 9659} = 1 \cdot 3.$$

$$O = \text{Outside diameter} = D + \frac{2}{P_n} = 1 \cdot 3 + \cdot 16 = 1 \cdot 466.$$

$$T = \text{Number marked on cutter} = \frac{N}{\text{Cos}^3\, a} = \frac{15}{\cdot 9} = 16.$$

$$L = \text{Lead of helix} = \pi D \cot a = 3 \cdot 1416 \times 1 \cdot 3 \times 3 \cdot 73 = 15 \cdot 23.$$

Gears

Gear on worm - - - - -	64
First stud wheel - - - - -	28
Second stud wheel - - - -	48
Gear on screw - - - -	72

12 Pitch Helical Gear Parallel Shafts

Ratio 1 *to* 1

C_a = Approximate centre distance = 2 in.
P_n = Normal pitch = 12.
N = Number of teeth = 24.
a = Helix angle = 15°.

$$D = \text{Pitch diameter} = \frac{N}{P_n \cos a} = \frac{24}{12 \times \cdot 9659} = 2 \cdot 07.$$

$$O = \text{Outside diameter} = D + \frac{2}{P_n} = 2 \cdot 07 + \frac{2}{12} = 2 \cdot 236.$$

$$T = \text{Number of teeth on cutter} = \frac{N}{\text{Cos}^3\, a} = \frac{24}{\cdot 9} = 26 \cdot 6.$$

$$L = \text{Lead of helix} = \pi D \cot a = 3 \cdot 1416 \times 2 \cdot 07 \times 3 \cdot 732 = 24 \cdot 269.$$

Gears

Gear on worm - - - - -	100
First stud wheel - - - - -	32
Second stud wheel - - - -	56
Gear on screw - - - - -	72

10 Pitch Helical Gear Shafts at Right Angles

Ratio 1 *to* 1.5

C_a = Approximate centre distance = 3·2 in.
P_n = Normal pitch = 10.
R = Ratio of gear to pinion = 1·5 to 1.

n = Number of teeth in pinion $= \dfrac{1\cdot41 C_a P_n}{R+1}$ for 45° = 18 teeth.

N = Number of teeth in gear $= nR = 18 \times 1\cdot5 = 27$.
a = Angle of helix gear = 45°.
β = Angle of helix pinion = 45°.

D = Pitch diameter of gear $= \dfrac{N}{\text{Cos } a \, P_n} \quad \dfrac{27}{\cdot7071 \times 10} = 3\cdot818$.

d = Pitch diameter of pinion $= \dfrac{}{\text{Cos } a \, P_n} \quad \dfrac{18}{\cdot7071 \times 10} = 2\cdot545$.

O = Outside diameter of gear $D + \dfrac{2}{P_n} = 3\cdot818 + \dfrac{2}{10} = 4\cdot018$ in.

o = Outside diameter of pinion $d + \dfrac{2}{P_n} = 2\cdot545 + \dfrac{2}{10} = 2\cdot745$ in.

T = Number of cutter to be used $= \dfrac{N}{\cdot353} = \dfrac{27}{\cdot353} = 76\cdot5$.

t = Number of cutter to be used $= \dfrac{n}{\cdot353} = \dfrac{18}{\cdot353} = 51$.

L = Lead of helix $\pi D = 3\cdot1416 \times 3\cdot818 = 12$ in.
l = Lead of helix $\pi D = 3\cdot1416 \times 2\cdot545 = 8$ in.

Wheels for Pinion		Wheels for Gear	
Gear on worm	64	Gear on worm	72
First stud wheel	32	First stud wheel	40
Second stud wheel	40	Second stud wheel	32
Gear on screw	100	Gear on screw	48

Milling Helical Gears

When the necessary change wheels to cut the given lead have been selected and placed in position, the machine table must be set to the correct angle, the angle

being obtained in the manner already given. The centre of the cutter must be exactly in line with the headstock centre before the table is moved, that is, when the cutter is equal on both sides of the centre.

Care should be taken to see that the wheel blank is firmly placed on its mandrel and is unlikely to slip, and also that at the end of each cut the table is either dropped, or the cutter pulled round so as to allow it to pass back over the work without touching it.

Cutters for Helical Gears

The cutters used for milling spur gears are also used for cutting helicals, but the numbers of the cutter used for a helix with a given number of teeth and a spur wheel having a similar number of teeth differ. Cutters of corresponding pitch are used, but the number of the cutter is not selected in the same manner.

To find the correct cutter, divide the actual number of teeth in the spiral wheel by the cube of the cosine of the tooth angle; the quotient will be the number of teeth for which the cutter should be selected, according to the spur gear system.

Example.—A helix gear has 15 teeth with a helix angle of 45°. Find the cutter.

Then $15 \div \text{cosine}^3\ 45°$. The cosine of 45° is 0.7071 and $15 \div (0.7071)^3 = 42$, which is the number for which the cutter must be selected. This would be No. 3, according to the involute system.

Tables of Approximate Cutting Angles

The following tables of approximate cutting angles, published by Messrs Brown & Sharpe, will be found extremely useful in many of the gear cutting operations done on the universal milling machine.

TABLE OF APPROXIMATE ANGLES FOR CUTTING SPIRALS

TANGENT OF ANGLE OF SPIRAL = $\frac{\text{CIRCUMFERENCE OF CUTTER, DRILL, OR MILL}}{\text{LEAD IN INCHES TO ONE TURN}}$

C = CIRCUMFERENCE OF CUTTER, DRILL, OR MILL
L = LEAD IN INCHES TO ONE TURN
T = TANGENT OF ANGLE OF SPIRAL

$T=\frac{C}{L}$ $L=\frac{C}{T}$

NOS. OF TEETH IN GEARS FURNISHED WITH MACHINE
24(2) 28 32 40 44 48 56 64 72 86 100

THE LEAD IN INCHES TO ONE TURN = $\frac{\text{10 × GEAR ON WORM × 2ND GEAR ON STUD}}{\text{GEAR ON SCREW × 1ST GEAR ON STUD}}$

DIAMETER OF CUTTER, DRILL, OR MILL

GEAR ON WORM	1ST GEAR ON STUD	2ND GEAR ON STUD	GEAR ON SCREW	LEAD IN INCHES TO ONE TURN	⅛"	¼"	⅜"	½"	⅝"	¾"	⅞"	1"	1¼"	1½"	1¾"	2"	2¼"	2½"	2¾"	3"	3¼"	3½"	3¾"	4"	4¼"	4½"	4¾"	5"	5¼"	5½"	5¾"	6"
24	72	28	86	1.085	20	36	47¼																									
24	72	32	86	1.240	17½	32¼	43½	51¾																								
24	72	40	100	1.333	16½	30½	41½	49¾																								
24	48	28	100	1.400	15¾	29¼	40	48¼																								
24	64	40	100	1.500	14¾	27¾	38¼	46½	52½																							
28	56	32	100	1.600	13¾	26¼	36¼	44½	50¾																							
24	72	44	86	1.706	13	24¾	34½	42½	49																							
24	64	48	100	1.800	12¼	23½	33¼	41	47½	52¼																						
24	40	32	100	1.920	11½	22¼	31½	39¼	45¾	50¾																						
28	64	40	86	2.035	11	21	30	37¾	44	49¼																						
24	72	56	86	2.171	10½	20	28½	35¾	42	47¼	51¾																					
24	64	44	72	2.292	9¾	19	27¼	34¼	40½	45¾	50¼																					
28	64	56	100	2.450	9	17¾	25¾	32¾	38¾	44	48¼	52																				
40	86	56	100	2.605	8½	16¾	24¼	31	37	42	46½	50¼																				
40	56	28	72	2.778	8	15¾	23	29½	35¼	40¼	44¾	48½																				
24	56	44	64	2.946	7½	15	21¾	28	33½	38¾	43	46¾																				
24	86	72	64	3.140	7	14	20¼	26½	32	37	41¾	45	51¼																			
28	56	48	72	3.333	6¾	13¼	19¼	25¼	30½	35¼	39¼	43¼	49¾																			
48	44	28	86	3.552	6¼	12½	18¼	23¾	29	33½	37¾	41½	47¾	53																		
44	56	48	100	3.771	6	11¾	17¼	22½	27½	32	36	39¾	46¼	51¼																		
72	100	48	86	4.019	5½	11	16¼	21¼	26	30½	34¼	38	44¼	49¼																		
64	48	32	100	4.267	5¼	10½	15½	20¼	24¾	29	32¾	36¼	42½	47¾	52½																	
56	48	28	72	4.537	5	9¾	14½	19	23½	27¼	31¼	34¾	41	46	50½																	
56	64	40	72	4.861	4¾	9¼	13½	18	22	25¾	29½	32¾	39	44	48½	52¼																

EXAMPLE ILLUSTRATING USE OF TABLE

DIAMETER OF CUTTER, DRILL, OR MILL .... = 1¼
LEAD IN INCHES TO ONE TURN .... = 3.140
REQUIRED ANGLE TO NEAREST QUARTER DEGREE TO SET SADDLE OF UNIVERSAL MILLING MACHINE = 51¼°

TABLE OF APPROXIMATE ANGLES FOR CUTTING SPIRALS

$$\text{Tangent of Angle of Spiral} = \frac{\text{Circumference of Cutter, Drill, or Mill}}{\text{Lead in Inches to One Turn}}$$

C = Circumference of Cutter, Drill, or Mill
L = Lead in Inches to One Turn
T = Tangent of Angle of Spiral

$T = \frac{C}{L}$ $L = \frac{C}{T}$

Nos. of Teeth in Gears Furnished with Machine
24 (2) 28 32 40 44 48 56 64 72 86 100

$$\text{The Lead in Inches to One Turn} = \frac{10 \times \text{Gear on Worm} \times \text{2nd Gear on Stud}}{\text{Gear on Screw} \times \text{1st Gear on Stud}}$$

Gear on Worm	1st Gear on Stud	2nd Gear on Stud	Gear on Screw	Lead in Inches to One Turn	⅛"	¼"	⅜"	½"	⅝"	¾"	⅞"	1"	1¼"	1½"	1¾"	2"	2¼"	2½"	2¾"	3"	3¼"	3½"	3¾"	4"	4¼"	4½"	4¾"	5"	5¼"	5½"	5¾"	6"
56	48	44	100	5.133	4½	8¾	13	17	21	24¾	28¼	31½	37½	42½	47	50¾																
86	44	28	100	5.473	4	8¼	12¼	16	19¾	23¼	26¾	29¾	35¾	40¾	45	49	52¼															
100	48	24	86	5.814	3¾	7¾	11½	15	18¾	22	25¼	28½	34	39	43½	47¼	50½															
72	56	48	100	6.171	3¾	7¼	10¾	14¼	17¾	21	24	27	32½	37¼	41¾	45½	48¾	51¾														
72	56	44	86	6.578	3½	6¾	10¼	13½	16½	19¾	22¾	25½	30¾	35½	40	43¾	47	50	52¾													
56	32	40	100	7.000	3¼	6½	9½	12¾	15¾	18½	21½	24¼	29¼	34	38¼	42	45¼	48¼	51													
56	28	32	86	7.442	3	6	9	12	14¾	17½	20¼	23	27¾	32¼	36½	40¼	43½	46½	49¼	51¾												
72	40	44	100	7.920	2¾	5¾	8½	11¼	14	16½	19¼	21¾	26½	30¾	34¾	38½	41¾	44¾	47½	50	52¼											
56	32	48	100	8.400	2¾	5¼	8	10½	13¼	15¾	18	20½	25	29¼	33¼	36¾	40	43	45¾	48¼	50½	52½										
86	32	24	72	8.959	2½	5	7½	10	12½	14¾	17	19¼	23¾	27¾	31½	35	38¼	41¼	44	46½	48¾	50¾	52¾									
64	48	40	56	9.524	2¼	4¾	7	9¼	11¾	14	16	18¼	22½	26¼	30	33½	36½	39½	42¼	44¾	47	49	51	52¾								
100	44	32	72	10.101	2¼	4½	6¾	8¾	11	13	15¼	17¼	21¼	25	28½	31¾	35	37¾	40½	43	45¼	47½	49½	51¼	53							
86	40	32	64	10.750	2	4¼	6¼	8¼	10¼	12½	14¼	16¼	20	23¾	27	30¼	33¼	36¼	38¾	41¼	43½	45¾	47½	49½	51¼	52¾						
86	48	64	100	11.467	2	4	5¾	7¾	9¾	11½	13½	15¼	19	22¼	25½	28¾	31¾	34½	37	39½	41¾	43¾	45¾	47½	49¼	51	52½					
72	44	64	86	12.178	1¾	3¾	5½	7¼	9¼	11	12¾	14½	18	21¼	24¼	27¼	30¼	32¾	35½	37¾	40	42	44	46	47¾	49¼	50¾	52¼				
56	24	40	72	12.963	1¾	3½	5¼	7	8½	10¼	12	13½	16¾	20	23	25¾	28½	31¼	33¾	36	38¼	40¼	42¼	44	45¾	47½	49	50½	51½	51¾		
86	40	64	100	13.760	1¾	3¼	5	6½	8	9¾	11¼	12¾	16	19	21¾	24½	27¼	29¾	32	34½	36½	38½	40½	42¼	44¼	45¾	47¼	48¾	50¼	51½	52¾	
86	44	48	64	14.659	1½	3	4½	6	7½	9	10½	12	15	17¾	20½	23¼	25¾	28¼	30½	32¾	34¾	36¾	38¾	40½	42¼	44	45½	47	48½	49¾	51	52
64	32	56	72	15.556	1½	3	4¼	5¾	7¼	8½	10	11½	14¼	16¾	19½	22	24½	26¾	29	31¼	33¼	35¼	37¼	39	40¾	42¼	43¾	45¼	46¾	48	49¼	50½
72	40	44	48	16.500	1¼	2¾	4	5½	6¾	8¼	9½	10¾	13½	16	18½	20¾	23¼	25½	27¾	29¾	31¾	33¾	35½	37¼	39	40½	42	43½	45	46¼	47½	48¾
100	44	56	72	17.677	1¼	2½	3¾	5	6¼	7½	8¾	10	12½	15	17¼	19½	21¾	24	26	28	30	31¾	33¾	35½	37	38¾	40¼	41½	43	44¼	45½	46¾
86	28	44	72	18.770	1¼	2½	3½	4¾	6	7¼	8¼	9½	11¾	14	16¼	18½	20¾	22¾	24¾	26¾	28½	30½	32	33¾	35½	37	38½	40	41¼	42½	44	45
100	28	48	86	19.934	1¼	2¼	3½	4½	5½	6¾	7¾	9	11¼	13¼	15½	17½	19½	21½	23½	25¼	27	28¾	30½	32¼	33¾	35¼	36¾	38¼	39½	41	42¼	43½
86	32	44	56	21.12	1	2¼	3¼	4¼	5¼	6½	7½	8½	10½	12½	14½	16½	18½	20½	22¼	24	25¾	27½	29¼	30¾	32¼	33¾	35¼	36½	38	39¼	40½	41¾

TABLE OF APPROXIMATE ANGLES FOR CUTTING SPIRALS

$$\text{Tangent of Angle of Spiral} = \frac{\text{Circumference of Cutter, Drill, or Mill}}{\text{Lead in Inches to One Turn}}$$

C—Circumference of Cutter, Drill, or Mill
L—Lead in Inches to One Turn
T—Tangent of Angle of Spiral

$T = \frac{C}{L}$ $L = \frac{C}{T}$

Nos. of Teeth in Gears Furnished with Machine
24(2) 28 32 40 44 48 56 64 72 86 100

$$\text{The Lead in Inches to One Turn} = \frac{10 \times \text{Gear on Worm} \times \text{2nd Gear on Stud}}{\text{Gear on Screw} \times \text{1st Gear on Stud}}$$

Diameter of Cutter, Drill, or Mill

Gear on Worm	1st Gear on Stud	2nd Gear on Stud	Gear on Screw	Lead in Inches to One Turn	1/8"	1/4"	3/8"	1/2"	5/8"	3/4"	7/8"	1"	1 1/4"	1 1/2"	1 3/4"	2"	2 1/4"	2 1/2"	2 3/4"	3"	3 1/4"	3 1/2"	3 3/4"	4"	4 1/4"	4 1/2"	4 3/4"	5"	5 1/4"	5 1/2"	5 3/4"	6"
72	28	56	64	22.50	1	2	3	4	5	6	7	8	10	11¾	13¾	15½	17¼	19¼	21	22¾	24½	26	27¾	29½	30¾	32½	33½	35	36½	37¼	38¾	40
64	40	72	48	24.00	1	2	2¾	3¾	4¾	5½	6½	7½	9¼	11	13	14¾	16½	18¼	19¾	21¼	23	24½	26¼	27½	29	30¾	31¾	33¼	34½	35¾	37	38½
100	64	72	44	25.57	1	1¾	2½	3½	4¼	5¼	6½	7¼	8¾	10¼	12¼	13¾	15½	17	18¾	20¼	21¾	23¼	24¾	26¼	27½	29	30¼	31½	32¾	34	35¼	36½
100	72	86	44	27.15		1½	2¼	3¼	4¼	5	5¾	6½	8¼	9¾	11¼	13	14½	16¼	17¾	19¼	20½	22	23½	24¾	26¼	27½	28¾	30	31¼	32½	33¾	34¾
86	40	64	48	28.67		1½	2¼	3¼	4	4¾	5½	6¼	7¾	9¼	10¾	12½	13¾	15¼	16¾	18¼	19½	21	22½	23¾	25	26¼	27½	28¾	30	31	32¼	33¼
86	32	64	56	30.71		1¼	2¼	3	3¾	4¼	5	5¾	7¼	8¾	10¼	11½	13	14½	15¾	17	18¼	19¾	21	22¼	23½	24¾	26	27	28¼	29½	30½	31½
72	32	64	44	32.73		1¼	2	2¾	3½	4	4¾	5½	6¾	8¼	9½	10¾	12¼	13½	14¾	16	17¼	18½	19¾	21	22¼	23½	24¾	25¾	26¾	27¾	29	30
100	24	40	48	34.72		1¼	2	2½	3¼	4	4½	5¼	6½	7¾	9	10¼	11½	12¾	14	15¼	16½	17½	18¾	20	21	22¼	23¼	24¼	25¼	26¼	27¼	28¼
100	24	64	72	37.04		1¼	1¾	2½	3	3¾	4¼	4¾	6	7¼	8½	9¾	10¾	12	13¼	14¼	15½	16½	17½	18½	19½	21	22	23	24	25	26	27
100	28	44	40	39.29		1¼	1¾	2¼	2¾	3½	4	4½	5¾	6¾	8	9	10¼	11¼	12¼	13¼	14¼	15¼	16¼	17¼	18¼	19¼	20¼	21¼	22¼	23¼	24¼	25¼
86	24	56	48	41.81		1	1½	2¼	2¾	3¼	3¾	4¼	5¼	6½	7½	8¼	9½	10¾	11¾	12¾	13¾	14¾	15¾	16¾	17¾	18¾	19¾	20½	21½	22½	23½	24½
100	28	40	32	44.64		1	1½	2	2½	3	3½	4	5	6	7	8	9	10	11	12	13	13¾	14¾	15¾	16¾	17¾	18¾	19½	20½	21½	22	23
100	28	64	48	47.62		1	1½	2	2½	2¾	3½	3¾	4¾	5¾	6½	7½	8½	9¼	10¼	11¼	12	13	14	14¾	15½	16½	17¼	18	19	20	20¾	21½
86	28	72	44	50.26		1	1¼	1½	2¼	2½	3¼	3½	4½	5¼	6¼	7¼	8	9	9¾	10½	11½	12½	13¼	14	14¾	15¾	16½	17¼	18¼	19	19¾	20½
100	28	48	32	53.57			1¼	1½	2	2¼	3	3¼	4¼	5	5¾	6¾	7	8¼	9¼	10	10¾	11½	12¼	13	14	14¾	15¼	16¼	17	17¾	18½	19½
100	28	64	40	57.14			1¼	1½	2	2¼	2¾	3¼	4	4¾	5½	6¼	7	7¾	8½	9¼	10¼	11	11¾	12½	13¼	14	14¾	15½	16	16¾	17½	18½
100	24	64	44	60.61			1	1½	1¾	2¼	2½	3	3¾	4½	5¼	6	6¾	7¾	8	8¾	9¾	10¼	11	11¾	12½	13	13¾	14½	15½	16	16½	17½
100	28	86	48	63.99				1½	1¾	2	2½	2¾	3½	4¼	5	5½	6¼	7	7¾	8½	9	9¾	10½	11	11¾	12½	13	13¾	14½	15	15¾	16½
72	24	64	28	68.57				1½	1¾	2	2½	2¾	3½	4	4¾	5¼	6	6¾	7¼	7¾	8½	9	9¾	10½	11	11¾	12½	13	13½	14¼	14¾	15½
86	24	64	32	71.67				1½	1½	2	2¼	2½	3¼	3¾	4½	5	5¾	6½	6¾	7½	8	8½	9¼	10	10½	11¼	11¾	12½	13	13½	14¼	14¾
100	24	72	40	75.00				1¼	1½	1¾	2	2½	3	3½	4¼	4¾	5½	6	6½	7¼	7¾	8½	9	9½	10	10¾	11½	11¾	12½	13	13½	14
100	24	64	32	83.33				1	1¼	1½	2	2¼	2¾	3¼	3¾	4¼	4¾	5½	6	6½	7	7½	8	8½	9	9¾	10½	10¾	11½	11¾	12¼	12½
100	24	86	40	89.59				1	1¼	1½	1¾	2	2½	3	3½	4	4½	5	5½	6	6½	7	7½	8	8½	9	9½	10	10½	11	11½	12
100	24	64	28	95.24					1¼	1½	1¾	2	2¼	2¾	3¼	3¾	4¼	4¾	5¼	5¾	6	6½	7	7½	8	[illegible]	[illegible]	9¼	9¾	10¼	10¾	11¼

Rules for Worm Gearing

The following notation, referring to Figs. 401 and 402, is used in the formula given for worms and worm wheels.

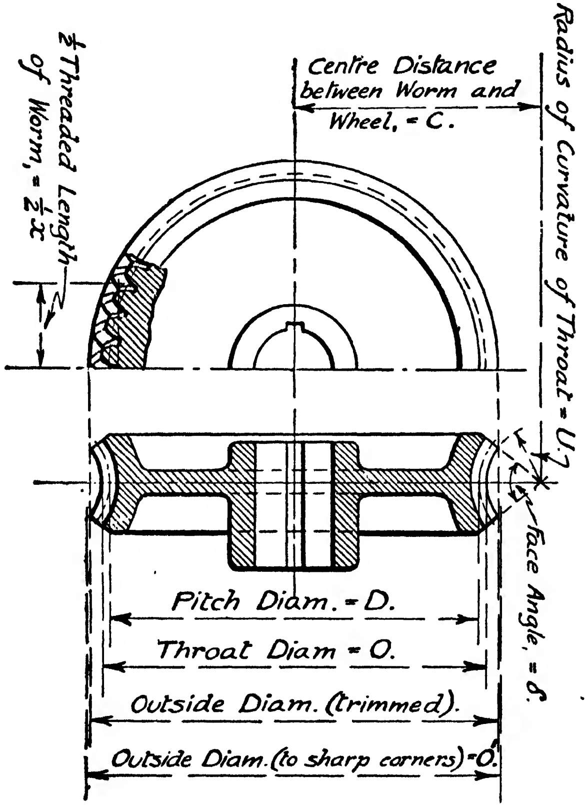


FIG. 401.—Formula for Worm Wheels.

In taking the number of threads in the worm "n" is the number of separate threads, and does not refer to the pitch or the number of threads per inch:—

Let n = Number of threads.
,, P = Circular pitch of wheel and linear pitch of worm.
,, S = Addendum.
,, l = Lead of worm.
,, D = Pitch diameter of worm wheel.
,, O = Throat diameter of worm wheel.
,, O′ = Outside diameter of worm wheel.
,, d = Pitch diameter of worm.
,, C = Root diameter of worm.
,, o = Outside diameter of worm.
,, N = Number of teeth in worm wheel.
,, W = Whole depth of worm tooth.
,, T = Width of thread tool at end.
,, a = Face angle of worm wheel.
,, β = Helix angle of worm.
,, C = Distance between centres.
,, x = Threaded length of worm.
,, U = Radius of curvature of worm wheel throat.

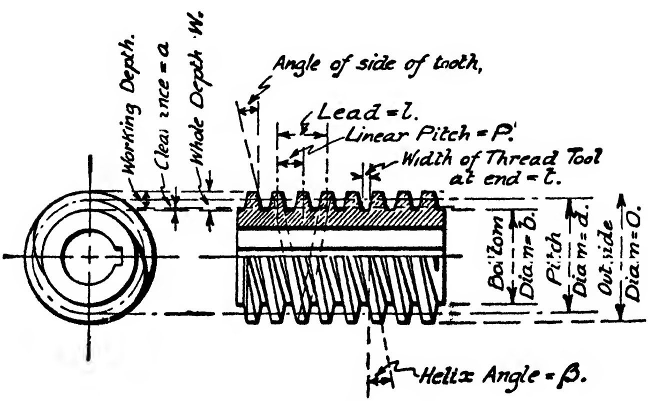


FIG. 402.—Formula for Worm Gearing.

Formula for Worm Gearing

To obtain	Rule.	Formula.
Centre Distance between Worm and Gear	Add together the pitch diameter of the worm and the pitch diameter of the worm-wheel, and divide the sum by 2.	$C = \frac{D + d}{2}$
Linear Pitch	Divide the lead by the number of threads.—It is understood, of course, that by the number of threads is meant, not the number of threads per inch, but the number of threads in the whole worm—one, if it is single-threaded, four, if is quadruple-threaded, etc.	$P^1 = \frac{l}{n}$
Outside Diam. of Worm	Add together the pitch diameter and twice the addendum.	$o = d + 2s$
Minimum Length of Worm for Complete Action	Subtract four times the addendum of the worm thread from the throat diameter of the wheel, square the remainder, and subtract the result from the square of the throat diameter of the wheel. The square root of the result is the minimum length of worm advisable.	$x = \sqrt{o^2 - (o - 4s)^2}$
Pitch Diam. of Worm	Subtract the pitch diameter of the worm-wheel from twice the centre distance.	$d = 2C - D$
Addendum of Worm Tooth	Multiply the linear pitch by 0·3183.	$s = 0{\cdot}3183\ P^1$
Pitch. Diam. of Worm	Subtract twice the addendum from the outside diameter.	$d = o - 2s$
Pitch Diam. of Worm-Wheel	Multiply the number of teeth in the wheel by the linear pitch of the worm, and divide the product by 3·1416.	$D = \frac{NP^1}{3{\cdot}1416}$
Diam. of Worm-Wheel to Sharp Corners	Multiply the throat radius by the cosine of half the face angle, subtract this quantity from the throat radius, multiply the remainder by 2, and add the product to the throat diameter of the worm-wheel.	$o^1 = 2\left(U - U \cos\frac{\delta}{2}\right) + o$
Throat Diam. of Worm-Wheel	Add twice the addendum of the worm tooth to the pitch diameter of the worm-wheel.	$o = D + 2s$
Radius of Worm-Wheel Throat	Subtract twice the addendum of the worm tooth from half the outside diameter of the worm.	$U = \frac{o}{2} - 2s$
Helix Angle of Worm	Multiply the pitch diameter of the worm by 3·1416, and divide the product by the lead; the quotient is the cotangent of the tooth angle of the worm.	$\cot\beta = \frac{3{\cdot}1416d}{l}$
Width of Thread Tool at End	Multiply the linear pitch by 0·31.	$t^1 = 0{\cdot}31\ P^1$
Whole Depth of Worm Tooth	Multiply the linear pitch by 0·6866.	$W = 0{\cdot}6866\ P^1$
Bottom Diam. of Worm.	Subtract twice the whole depth of tooth from the outside diameter.	$b = o - 2W$

In Fig. 403 a worm of standard shape thread is given in part section. This thread has the same dimensions as

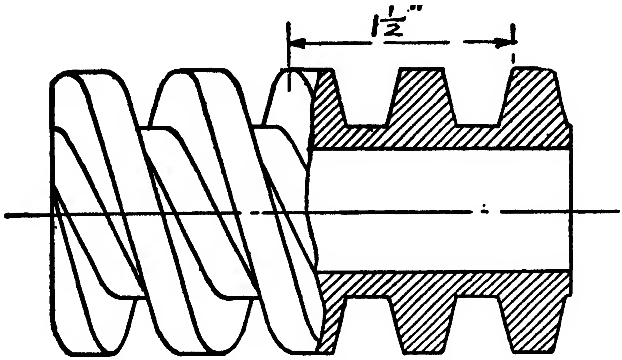


FIG. 403.—Double-Threaded Worm, 1½ in. Lead.

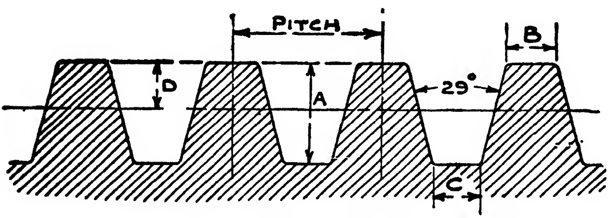


FIG. 404.—Proportions of Worm Threads.

an involute rack tooth of the same linear pitch. The proportions, as shown in Fig. 404, are:—

A=0·6866 of the pitch.
B=0·3354 ,, ,,
C=0·3100 ,, ,,
D=0·3183 ,, ,,

A worm wheel is shown in Fig. 405, and the various dimensions can be obtained from the given formula. The worked out example gives the necessary calculations.

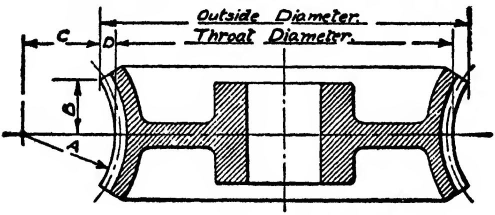
$$A = \tfrac{1}{2}\,\text{Pitch Diam.} - \frac{1}{\text{Diametral Pitch}}$$

$$C = \sqrt{A^2 - B^2}$$

$$D = A - C$$

$$\text{Throat Diameter} = \frac{\text{Number of Teeth} + 2}{\text{Diametral Pitch.}}$$

$$\text{Outside Diameter} = 2D + \text{Throat Diameter}$$



Example. 12 D.P. Worm Wheel, 40 Teeth.

Pitch Diam of Worm $= 2{\cdot}1''$. $B = 0{\cdot}5625''$.

Then – $A = 1{\cdot}05 - \frac{1}{12} = \underline{0{\cdot}967''}$. $C = \sqrt{0{\cdot}967^2 - 0{\cdot}5625^2} = \underline{0{\cdot}787''}$

$D = 0{\cdot}967 - 0{\cdot}787 = \underline{0{\cdot}180}$

Throat Diam. $= \frac{42}{12} = \underline{3{\cdot}5''}$ and Outside Diam. $= (0{\cdot}180 \times 2) + 3{\cdot}5 = \underline{3{\cdot}86''}$

FIG. 405.—Calculation for Worm Wheels.

Cutting Worm Wheels

Worm wheels cut in the milling machine are usually completed in two operations: first by gashing or cutting teeth in the periphery of the blank by means of a suitable involute gear cutter, and then finishing to size by means of a formed hob.

In the first operation, the dividing head is arranged for indexing the number of teeth in the wheel, and the cutter is set to the centre of the blank. (The cutter must be exactly central with the tailstock or dividing head centre when the table is set at zero.) The table is then set over

PROPORTIONS OF WORM THREADS

Circular Pitch (P)	Threads per Inch.	Diametral Pitch (DP).	Tooth above Pitch Line.	Working Depth of Tooth.	Clearance (C).	Depth of Space below Pitch Line.	Whole Depth of Tooth.	Thickness of Tooth on Pitch Line.	Width of Thread Tool at End.	Width of Thread at Top.
Inches.	$=\frac{1}{CP}$.	$DP=\frac{3{\cdot}1416}{CP}$.	$M=\frac{1}{DP}$	$=2M$.	$C=\frac{1}{20}CP$.	$=M+C$.	$=2M+C$.	$T=\frac{CP}{2}$.	$=\cdot31\times P$.	$=\cdot335\ P$.
2	½	1·5708	·6366	1·2732	·1000	·7366	1·3732	1·0000	·6200	·6700
1¾	4/7	1·7952	·5570	1·1141	·0875	·6445	1·2015	·8750	·5425	·5862
1½	⅔	2·0944	·4775	·9549	·0750	·5525	1·0299	·7500	·4650	·5025
1¼	⅘	2·5133	·3979	·7958	·0625	·4604	·8583	·6250	·3875	·4187
1	1	3·1416	·3183	·6366	·0500	·3683	·6866	·5000	·3100	·3350
⅞	1 1/7	4·1888	·2387	·4775	·0375	·2762	·5150	·3750	·2325	·2512
¾	1⅓	4·7124	·2122	·4244	·0333	·2455	·4577	·3333	·2066	·2233
½	2	6·2832	·1592	·3183	·0250	·1842	·3433	·2500	·1550	·1675
⅖	2½	7·8540	·1273	·2546	·0200	·1473	·2746	·2000	·1240	·1340
⅓	3	9·4248	·1061	·2122	·0166	·1227	·2288	·1666	·1033	·1117
2/7	3½	10·9956	·0909	·1819	·0143	·1052	·1962	·1429	·0886	·0957
¼	4	12·5664	·0796	·1591	·0125	·1021	·1716	·1250	·0775	·0838
2/9	4½	14·1372	·0707	·1415	·0111	·0818	·1527	·1111	·0689	·0745
⅕	5	15·7080	·0637	·1273	·0100	·0737	·1373	·1000	·0620	·0670
⅙	6	18·8496	·0531	·1061	·0083	·0614	·1144	·0833	·0517	·0559
1/7	7	21·9911	·0455	·0910	·0071	·0526	·0981	·0714	·0443	·0479
⅛	8	25·1327	·0398	·0796	·0062	·0460	·0858	·0625	·0387	·0419
1/9	9	28·2743	·0354	·0707	·0055	·0409	·0762	·0555	·0344	·0372
1/10	10	31·4159	·0318	·0637	·0050	·0368	·0687	·0500	·0310	·0335
1/12	12	37·6992	·0265	·0530	·0041	·0306	·0571	·0416	·0258	·0279
1/14	14	43·9824	·0227	·0454	·0035	·0262	·0489	·0357	·0221	·0239
1/16	16	50·2655	·0199	·0398	·0031	·0230	·0429	·0312	·0193	·0209
1/18	18	56·5488	·0176	·0352	·0027	·0203	·0379	·0277	·0172	·0186

The above table refers to single threads only. For multiple threads divide the thread sizes by the number of threads.

to the required angle. (This angle can be found by dividing the lead of the worm thread by the circumference of the pitch circle of the worm, which will give the tangent of the angle required.)

If the cutter is no larger in diameter than the hob, the depth of gashes should be slightly less than the whole

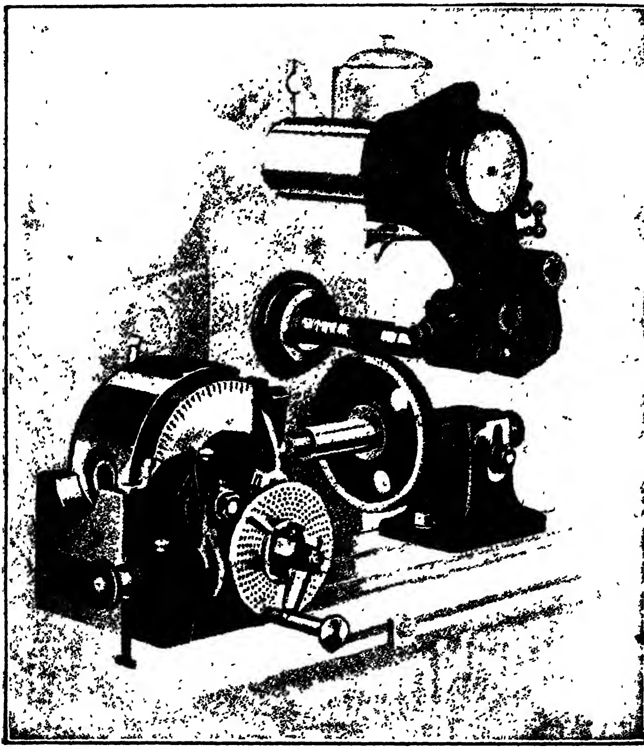


FIG. 406.—Method of Hobbing Gears.

depth of the teeth. Should the cutter be larger in diameter than the hob, then the whole depth of the tooth space should be marked off on the sides of the blank, and the gashes cut nearly to the line.

In cutting the gashes, it will be necessary to raise and lower the table for each tooth space; and after cutting one space, the index dial on the table raising shaft can be set to give the required amount of lift

The second operation consists of hobbing the gashed wheel; the carrier is removed from the wheel mandrel, and the wheel and mandrel can then revolve freely on the machine centres; the table is set at zero. The hob, in cutting, revolves the wheel, and the correct depth is obtained by working to marks, or by using a steel rule at the back of the knee to measure a distance equal to the centre distance of the worm and wheel from a line marked on the vertical slide to the top of the knee. This line on the vertical slide must indicate the position of the top of the knee when the index centres are at the same height as the centre of the machine spindle.

In the operation of hobbing a gashed wheel, the setting up is as shown in Fig. 406.

Hobs

Hobs for worm gears are not made exact duplicates of the corresponding worm, but have the tops of the teeth slightly rounded, and are provided with fillets at the root of the thread. The usual dimensions for hobs are:—

Outside dia. of hob = Outside dia. of worm + ·1 × Linear pitch of worm.
Root dia. of hob = Outside dia. of worm − 1·273 × Linear pitch of worm.

Standards

For the gears as used in practice there are a number of standards prepared by the representative bodies—in Great Britain by the B.S.I., in America by the A.S.A.—and these should always be consulted for important design work.

CHAPTER XIX

GEAR-HOBBING AND PLANING MACHINES

THE hobbing process of cutting gears is used to a very great extent in the modern engineering workshop. These machines will automatically generate spur and straight-face spiral gears and also worms. A wheel with perfect teeth would be one in which all the teeth were perfectly evenly spaced and correctly shaped, and it is very difficult to obtain such teeth in a machine cutting only one tooth at a time; for this reason a hobbing machine, or a machine operating upon more than one tooth, is to be preferred for this class of work.

The most important point to aim at in hobbing wheels is to obtain as nearly as possible a perfect hob, and at the same time have a machine which is fully strong enough and quite rigid. The shafts carrying the wheels and hobs should also be of ample strength, because, if the hob shafts are weak, there is a liability for them to twist, thereby causing the hob to lag behind the work, the result being that a tooth will be cut in which one side is convex and the other concave.

Fig. 407 shows a machine for automatically generating spur and helical gears, also worm wheels, by the hobbing process. All gears of the same pitch can be cut by the same hob, giving correctly formed teeth independent of their number.

The machine is fitted with a dividing arrangement

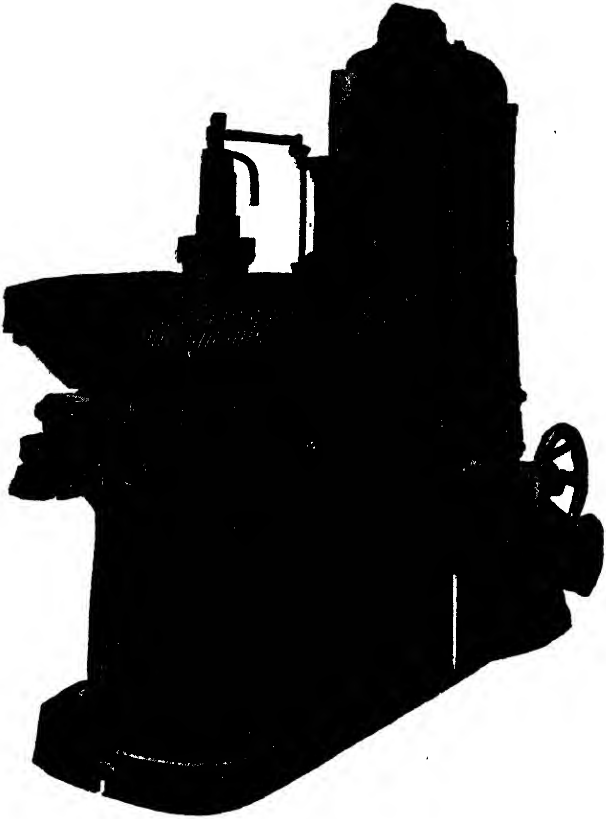


FIG. 407.—Gear-Hobbing Machine.

so that spur wheels may be cut with a single disc cutter, each tooth being divided by hand. This is very useful when a wheel of odd pitch has to be cut.

The Work Table is made of cast iron, with ample strength to resist all vibration. It has a large diameter bearing on the saddle with a deep central bearing, while lock nuts on the under side prevent any lifting tendency. The drive is through a hardened and ground worm and an accurately cut worm wheel, which are adjustable for wear. Ball-thrust washers are fitted to the worm.

The Saddle has a narrow guide and secure clamping device. It is provided with screw feed which may be operated either by hand or power. It is employed when cutting worm wheels, as the face of the blank is fed into the hob. A micrometer is provided for measuring the depth of tooth, and an automatic stop can be set to disengage the feed at the required depth of cut.

The arrangement of the gearing which permits a continuous cut saves time which would otherwise be occupied by the idle return stroke of the cutters. Rigid support is given to blanks of large diameter and no uneven heating of the work, with consequent inaccuracy, is experienced. Better finished work is produced, and considerably less grinding of cutters is necessary, owing to the large number of teeth engaged at the same time.

The Work Arbors have taper ends which fit into a bracket on the table, and are secured with a large right and left hand nut. An efficient stay provides a rigid bearing to the upper end, but can be easily removed if desired.

Rapid Power Traverse is fitted for quickly setting the hob, or withdrawing it after completion of cut.

The Hob Saddle has a long bearing on the column with a narrow guide. It is counterbalanced, and has adjustment by means of a taper gib. Hand and automatic feed is provided, and an automatic trip can be set to disengage the feed at any desired point.

The Hob is driven by accurately cut double helical

gearing and a powerful and steady drive is ensured, as the speed reduction is on the last pair of wheels. Six speeds in geometrical progression are obtained from the three-step cone and two-speed countershaft.

Fig. 408 illustrates a generating hob with helical teeth, the pitch of the thread being equal to the pitch of the gear teeth being generated. The speed of rotation of both

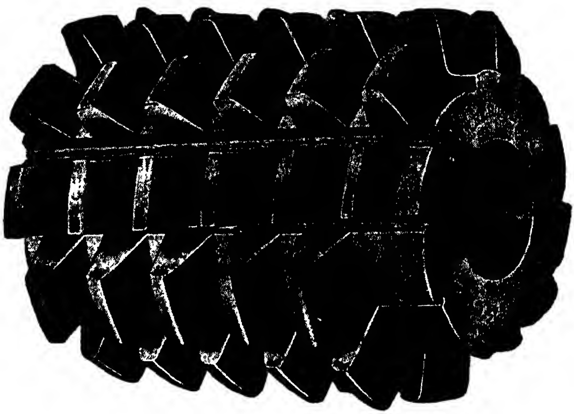


FIG. 408.—Hob for Generating Gears.

gear blank and hob are arranged to correspond, thus automatically ensuring correct dividing of the teeth and producing theoretically correct teeth. The setting of the machine is such as to give the desired tooth thickness when measuring on the pitch line.

Feeds for Hobbing.—The feeds for hobbing vary from about 0.02 to 0.2 in. per revolution of the gear. The following figures can be taken as approximate, and give the movement of the hob per revolution of the gear. The feed of the hob should in all instances be related to the number of teeth around a cross section and be proportioned

so that each tooth can cut a chip and not slide over the metal. Hence the following table is only a tentative suggestion :—

Material.	Feed.
Hard steel - - - - -	0·01
Medium steel - - - -	0·03
Mild steel - - - - -	0·04
Hard cast iron - - - -	0·03
Medium cast iron - - -	0·05
Soft cast iron - - - -	0·15

When hobbing the feed per revolution of the hob should be the same as for a spur gear of the same tooth size and pitch diameter, of the same material, and requiring the identical surface finish. But when estimating the time required for the hobbing operation it is necessary to take into account the longer length of tooth which has to be cut and :—

Length of tooth for helical gears = width of blank × sec. helix angle e

Change Gear for Helical Gear-Hobbing Machines

The change gears to be used for generating helical gears on gear-hobbing machines may be found by the following formula :—

$$\frac{L \div F}{(L \div F) \pm 1} \times \frac{P}{p} = \frac{S}{s},$$

in which

L = lead of helix.
F = feed per revolution.
P = product of driving gear for cutting spur gears with the same number of teeth.
p = product of driven gears for cutting spur wheels with same number of teeth.
S = product of driving gears for cutting helical gears.
s = product of driven gears for cutting helical gears.

In the formula, use + sign when gear and hob are of opposite "hand," and — sign when they are of the same "hand."

Example.—Two helical gears are to be cut on a gear-hobbing machine. Gear No. 1 has 30 teeth, 24.549 in. lead, and a feed of $\frac{1}{24}$ in. The change gears used on the machine for cutting a spur gear with 30 teeth have 48 driving gear and 60 driven gear. The hob and gear are of the same "hand." Gear No. 2 has 60 teeth, 49.098 lead, with a feed of $\frac{1}{16}$ in. Change gears used to cut a spur gear with 60 teeth, on this machine, have 48 and 40 teeth for the driving gears and 60 and 80 for the driven gears. The hob and gear are of the same "hand."

The data then is :—

80 Tooth Gear.		60 Tooth Gear.	
L	24·549	L	49·098
F	$\frac{1}{24}$	F	$\frac{1}{16}$
P	48	P	40 × 48
p	60	p	60 × 80

Calculations for Thirty Tooth Gear

By inserting the values given :—

$$\frac{L \div F}{(L \div F) - 1} = \frac{589{\cdot}176}{588{\cdot}176}$$

the above ratio can be simplified to the form—

$$\frac{589}{588} \text{ and by factoring to } \frac{19 \times 31}{12 \times 49}.$$

Now, multiply this value with the ratio of the gear for a 30 tooth spur gear—

$$\frac{19 \times 31}{12 \times 49} \times \frac{48}{60} = \frac{76 \times 31}{60 \times 49}.$$

Having obtained the gears, investigate what lead the gears will give. As an approximate ratio was used instead

of the real one, an approximate lead will only be obtained. To prove—

Assume $F = \frac{1}{24}$ and solve for L—

$$\frac{L \div F}{(L \div F) - 1} = \frac{589}{588}.$$

From this $L = 24.541$, which is nearly equal to the required lead.

The calculations for the 60 tooth gear are carried out in exactly the same manner as for the 30 tooth gear.

Gear Planers

A machine for planing the teeth of spur, chain, and helical gears is illustrated at Fig. 409. The design gives

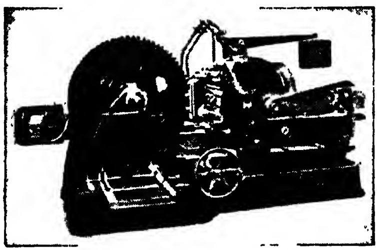


FIG. 409.—The Sunderland Gear Planer.
(By courtesy of Messrs Parkinson & Son Ltd., Shipley.)

a self-contained machine having an individual motor drive which eliminates the need for line shafting and overhead belts. The cutter slide has a quick return motion from a worm-driven crank disc, and is set square to cut spur gears or to the correct angle as when cutting helical gears.

The cutter box for holding the cutter may be set at

varying positions to suit the position of the wheel blank. The thrust of the cutter, except on small wheels, is taken by an adjustable rim stay, and two lengths of outer supports for the arbor are provided for use when the rim stay cannot be applied.

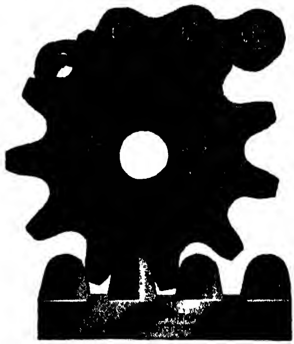


FIG. 410.—Wheel Cutter

Gear blanks are usually mounted on an arbor secured in the spindle socket, and the dividing wheel is securely fixed to the spindle, but the dividing worm may be disengaged and the spindle rotated freely, to test the tooth of the arbor or blank.

The feed motion, driving through one shaft, causes, simultaneously and in unison, the rotary motion of the blank and the travel of the cutter, for a distance of one, two, or more pitches according to

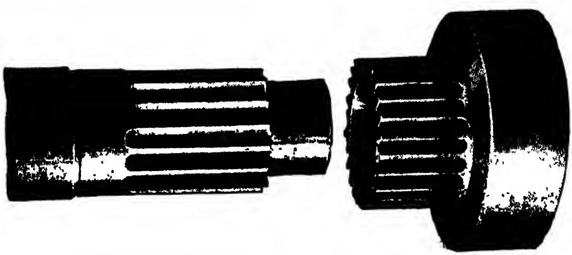


FIG. 411.—Cut Gears.

circumstances, whereupon the gear blank withdraws from the cutter, which returns to its original position, in order to operate on the next or succeeding segments of the gear

blank, which then re-engages the cutter. These movements repeated complete the gear. The feed operates intermittently on the return stroke of the cutter, and thus, during the cutting stroke, the dividing wheel and worm are at rest and not wearing. The rate of feed may be varied while running by a conveniently placed quick-change lever.

The process of cutting the teeth is a generative one, and has some of the advantages of hobbing. The involute system of tooth form is based on a rack, and the basis of the " Sunderland " planing system is using a rack as a cutter, and imparting to the cutter and gear the same

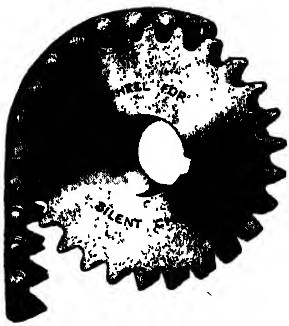


FIG. 412.—Cut Gear.

relative motion as a rack and gear wheel. The rack cutter operates directly on the gear, and one cutter will cut all numbers of teeth of the same pitch.

The action of the cutter is shown in Fig. 410 ; it will be seen that several teeth are in contact at the same time. The generative action is produced by traversing the cutter exactly like a rack, at a tangent to the pitch circle of the gear as it rotates, and exactly at the same speed. Figs. 411 and 412 show examples of work done by this type of machine.

Large-Scale Production of Bevel Gears

For the large-scale production of bevel gears special machines have, over the years, been designed, built, and brought to a high degree of perfection so that in some instances, when the tooth size is small, a well-shaped tooth true to size and form may be cut direct from the gear blank. However, when the tooth size becomes larger the general practice is to rough gash the gear blank on one machine and finish the teeth on another. Owing to the wide range of equipment available the reader should understand that the following comments only touch the fringe of the subject and in no way implies that one machine is better than another; such factors can only be ascertained under actual shop conditions. Nor is any attempt made to deal with hypoid bevel gear sets.

Roughing - out. — One such machine, made by Reineckers, is so designed that the milling head has a vertical movement in long guide-ways, and it is counterbalanced by a weight. The milling spindle is driven by a worm and wheel which gives a silent and even motion to the cutter, and the spindle has a taper hole to carry the different sizes of cutter arbors, together with means for accurate axial adjustment.

When cutting bevel gears there is an oscillating movement of the work table through a crank mechanism, and the table is set to the desired cone angle by means of a graduated scale. After this adjustment the table is securely fastened to the lower slide of the carriage and bed.

Another type of roughing-out machine made by the same firm operates either by the self-generating method on the Chambon system or by cutting each tooth separately, and can be used for the roughing-out of bevel gears by means either of worm hobs or ordinary formed cutters, and with certain limitations it can be used for the roughing-out of spiral bevel gears.

The use of roughing-out machines, as, for instance, those produced by the Gleason Co., facilitates production and effects a considerable saving of time by reason of the heavy first cuts which can be taken.

In the hobbing method the thickness of the tooth is reduced towards the apex of the bevel wheel in a manner which is virtually correct, and this leaves only a finishing cut of equal thickness on the tooth flanks to be done by the generator. A relatively small number of hobs is called for, but the method is only in general suitable for gears with a tooth length less than one-third of the height of the pitch cone. The action of this class of machine can be gathered from the view in Fig. 413. For very large production the Ford Company have an interesting type of machine which has as its principal feature an octagonal turret which is rotated continuously about a vertical axis. The gear blanks are clamped to its faces, each of which holds three—one above the other. The cutting spindle, which is vertical, carries three cutters which are situated opposite the three rows of gear blanks fastened to the faces of the turret so that the three gears are being operated on simultaneously. The revolving motion of the turret is a variable one: it moves slowly while the cutters are feeding through the blank, and then rapidly for bringing the opposite sides into the cutting position. Thus each cutter forms a groove, first in one side of the blank and then in the other, while once during each complete

rotation of the turret the gears are all indexed for cutting the next consecutive tooth space. Such specially built

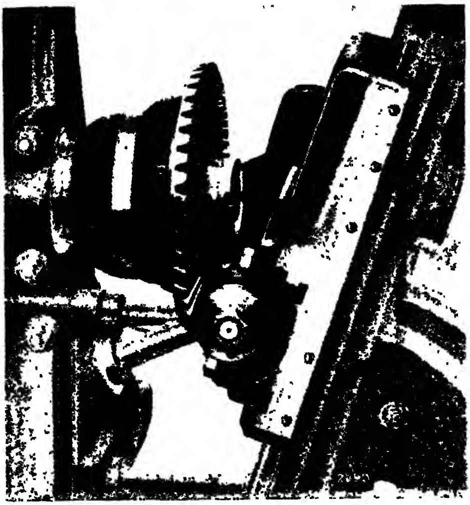


FIG. 413.—Roughing-out Bevel Gears.

machines are, of course, essential only in the case of very large productions.

Generating Machines.—The production of bevel gearing is analogous to the production of spur gearing in respect that the motion of the tool is controlled by the form of the tooth—that is, the crown wheel—in the same way that the cutting of spur-gear teeth is based upon the motion of the rack. The crown wheel may for

all practical purposes be considered as a circular rack, as shown in Fig. 414. It is, as will be observed, of larger diameter than is necessary to mesh with the gear *c* being cut, and it engages a master gear *b* keyed to the same

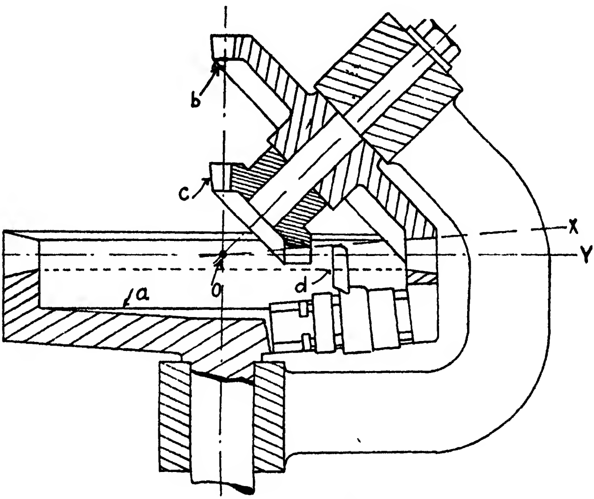


FIG. 414.—Generating Bevel Gear.

shaft as that of the gear being cut, and it is formed on the same pitch cone. Supposing the teeth of the crown gear, instead of being relatively narrow, as shown, were extended clear of the vertex o, they would mesh properly with the gear being cut.

The tooth, as indicated, has a line of movement such that the point of the tool *d* travels along the line o-x,

which is the corner of a tooth of a supposed extension of the crown gear. This crown gear, also sometimes referred to as a plane wheel, has a plane face, and the cutting edge of the tooth is straight and set so as to mesh with the face of the tooth. When reciprocated by suitable mechanism, to be described later, the cutting edge represents the face of the assumed crown gear tooth. Presuming, now, that the master gear and the crown gear are rolled together, and the reciprocating tool starts in at one side of the gear to be cut and passes out at the other, the straight cutting edge of the tooth will generate one side of a tooth in the gear to be cut in the same way as if the extended tooth of the crown gear were rolling its shape on one side of the tooth of a plastic blank.

This simple mechanism is added to by some provision for cutting both sides of the tooth, and for the indexing of the work from one tooth to another so as to complete the gear, while, in addition, arrangements have to be made to obtain a machine adjustable for bevel gears at all angles, number of teeth, and diameters within its range.

This is the basis of the Bilgram system, but in place of the crown gear and master gear being rotated together the tool remains stationary so far as the angular position is concerned while the frame is rotated about the axis of the crown gear, thus rolling the master gear on the latter and causing the work to be rolled in its proper relation to the tool. In place, however, of using crown and master gears a section of the pitch cone of the master gear is used which rolls on a plane surface, representing the pitch surface of the crown gear. Slipping of the two surfaces is prevented by an arrangement of steel tapes, to become apparent presently.

Essential Features of Automatic Gear Planers (Reinecker-Bilgram System).—The three views in Figs. 415, 416, and 417 show this machine suitable for straight or spiral teeth with a movable cutting head for bevels with long shafts, Fig. 416 showing it cutting a

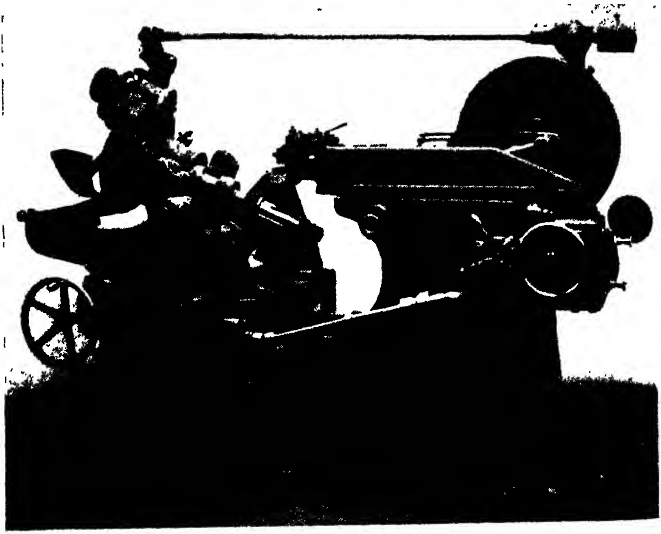


FIG 415.

spiral bevel pinion, while Fig. 417 is a view of a crown wheel being cut. The line diagram in Fig. 418 supplements these views, and, taken in conjunction with them, it serves to make the whole action clear.

The tool-holder K receives its motion by the ram J, while the linkshaft H effects the feed and the generating motion.

The stroke of the ram is regulated as to its length by means of the slot at J according to the thickness of the tooth to be planed, while the connecting rod can be shifted at the ram in its longitudinal direction according to the diameter of the work-piece. Starting at the curved groove L, which is drawn into the large driving wheel, the tool-lifter K, during the return stroke of the ram, is

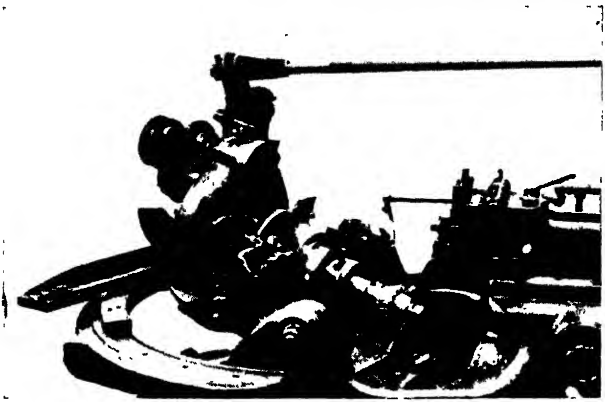


FIG. 416.

lifted out of the tooth space by a lever and eccentric mechanism. In addition, the tool-lifter can be held in position by the handle O. In its cross and vertical direction the tool-lifter can be regulated at the head of the ram by means of a socket wrench and a screwed spindle.

Starting now from the linkshaft H, all the setting attachment with the dividing head is slowly oscillated by means of the worm wheel Q, also visible in Fig. 415.

around the vertical axis, while, by means of adjustable stops, this oscillating motion can be thrown out of gear automatically. When the machine is stopped the oscillating motion can also take place by hand through a

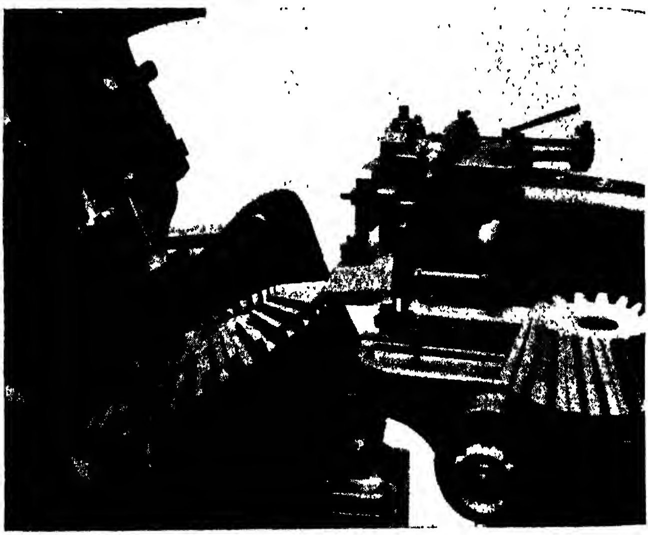


FIG. 417.—View of Reinecker Machine Cutting Crown Gear.

hand wheel. Furthermore, the whole setting arrangement can be turned round the horizontal axis through the hand wheel U, according to a graduated scale V for setting the base angle of the tooth. On the setting arrangement the dividing head may be set around the horizontal axis

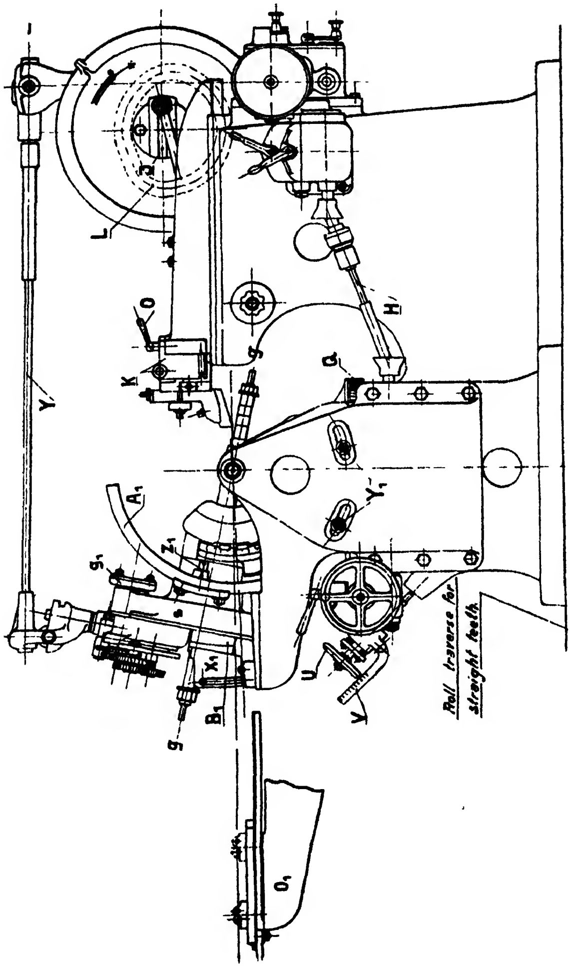


FIG. 418.—Cutting Bevel Gears.

by the ratchet wheel and worm wheel, according to another graduated scale and a vernier, so that the inclined axis of the work can be made to swivel in accordance with the pitch-cone angle of the wheel being cut. After setting, the position of the dividing heads is fixed by clamp screws. With the interchangeable work arbor the dividing spindle is arranged with endwise axial adjustment inside the dividing head, two guide brackets supporting this arbor at the front and rear of the work-piece. The larger roll cones are fastened to the traverse, which is held by the segments A_i. According to the pitch angle, the segments are regulated at the dividing head after this is screwed down again. The smaller roll cones are set at the roll frame B_i, which is also adjustable.

The axis of the wheel being cut passes, as may be observed, through the vertical axis of the machine, and if it is swung with the bevel gear around the axis, the same movement produces a rotation of the bevel gear around its own axis by reason of the effect of the roll cone and of the aforementioned steel bands. It is both these motions combined which produce the same movement of the bevel gear as if it were unrolled upon its basic plane wheel.

Oscillation around the vertical axis is effected through the worm wheel shown in the view in Fig. 415, and denoted by Q in the line drawing, and on which the dividing head is fixed and adjusted. Rotation round the axis of the wheel, however, takes place by the unrolling of the cone upon the steel bands. The roll cone is part of a cone surface, and the start of the band being at the lower horizontal plane, the wound-up part of the band can join closely to the cone plane without causing side pressures.

The general form of the cutting tool is shown in

Fig. 419. It has the form of a prismatic bar, and when in position it differs from the planing direction by the elevating angle β. Its cross-section is such that in vertical elevation it forms an isosceles triangle with the apex angle α of 15°, which corresponds to the usual pressure angle. While theoretically a bevel gear can be

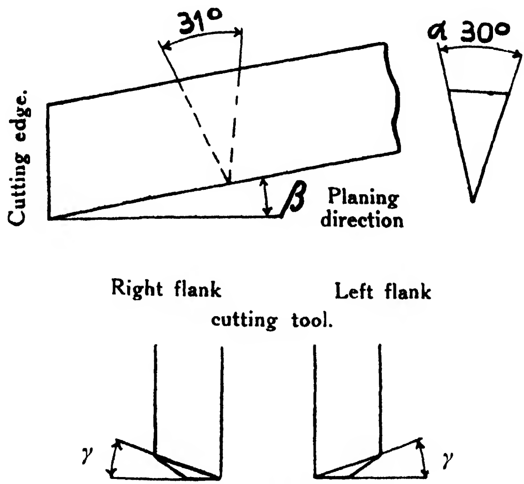


FIG. 419.—Cutting Tool for Bevel Gears.

cut with only one cutting tool, three different tools are used in practice, as the tool-holder in Fig. 417 will indicate. One of these, for the middle cut, has its face at right angles to the planing direction, while the two flank tools have their faces inclined under a cutting angle γ towards the planing direction, the cutting edge thereat remaining in its vertical position.

Circular Cutters: The Fellows System.—As

opposed to the rack cutter, which is the basis of the Sunderland process, there is the Fellows circular cutter; its form is shown in Fig. 420, and its action represented in Fig. 421.

One of the essentials of efficient and accurate commercial gear cutting is that the cut should be distributed over the greatest possible area. Fig. 421 illustrates how this is complied with in the case of a 6/8-pitch 3-in. cutter

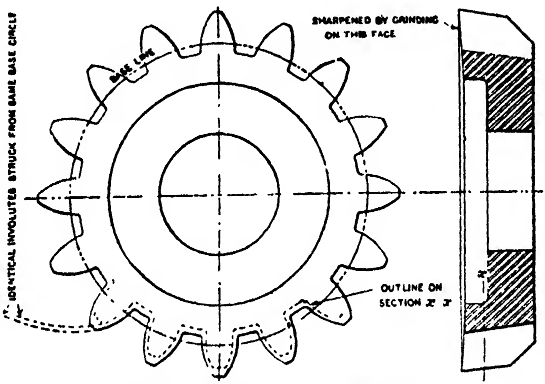


FIG. 420.—Gear Cutter (Fellows).

having a $\frac{5}{8}$-in. cutting surface per tooth—or a total cut of $11\frac{1}{4}$ in. In addition, the manner in which this cutter is presented to the work is such that the cutting edge which finishes the involute outline of the gear tooth does the least amount of cutting. All the heavy cutting is done with that portion of the tool not used to finish the accurate surfaces of the gear tooth, so that the finishing portion of the cutting tool is lengthened, and the cutter can be given a coarser feed and at the same time produce a fine finish.

Cutter and work rotate together, the cutter having a reciprocating motion, of course, similar to that of a planing tool. The outlines show the various positions which the cutting edge will occupy for each successive stroke, and the distance between any two adjacent outlines at any one point is the thickness of the chip at that point, and one of these chip sections is shown in hatched section; it will be seen that the thick part of the chip comes in the middle of the tooth space away from the finished

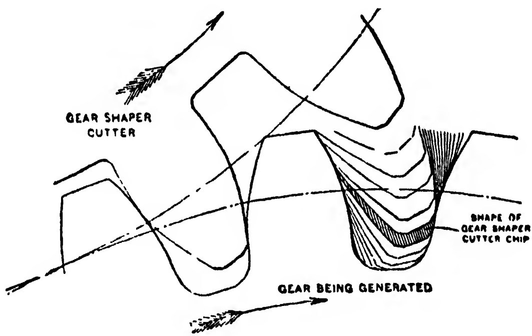


FIG. 421.—Action of Fellows Cutter.

surface. As the chip approaches the finished surface its thickness is greatly reduced, this being the correct condition for a fine finish. In the figure the thickness of the chip is exaggerated. As opposed to the milling cutter, which produces a wedge-shaped chip, that of the gear shaper is of full thickness for the full length of stroke, enabling the cutter at once to get below the crust of the metal, thus eliminating risk of deflection. This latter point is of special importance in the case of gears cut from tough alloy steel; as the cutter has an idle

return stroke, it is efficiently cooled. This type of machine cuts internal gears, both spiral and spur.

A Fellows machine is shown in Fig. 422.

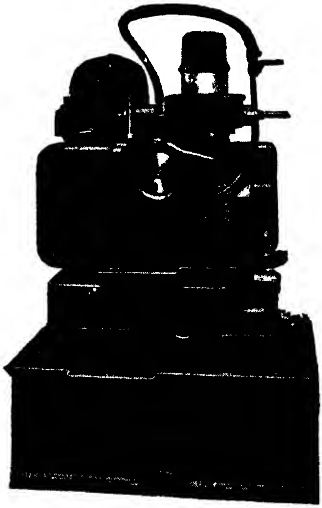


FIG. 422.—Photo View of Fellows Gear Shaper.

Hardening and Grinding.—There are a number of important subsidiary operations in connection with the production of modern gears, and more particularly those which are assembled in gear boxes of automobiles and machine tools, and run at high speeds in conjunction with a change-speed mechanism, which may involve sliding of the gears into and out of mesh with one another. The last-named motion calls for chamfering of the gear teeth, whilst before machining the material should be correctly

heat treated to remove any stress and at the same time to place the metal in a good condition for the various metal-cutting operations; after the final machining heat treating to give an excellent wear-resisting surface; and finally grinding or lapping to remove any slight surface imperfection.

Good wearing quality calls for a hard tooth surface, while conditions of strength require toughness, which has led to the general practice of case-hardening of gears after the teeth have been cut. Finishing the profile is done by grinding to remove any distortion due to the hardening operation. Heat treatment of gears is an important process and commences initially with the stampings and it is necessary to place the steel in a suitable condition for machining. Moreover, it brings the material into a homogeneous condition by eliminating molecular strains which are set up by the forging, stamping, or rolling operations. If this process is not done correctly, not only is the steel difficult to machine, liable to tear and rapidly to blunt the cutters, but the risk of warping during hardening is materially increased. To outline any general procedure is apt to be misleading, as the different grades require different treatment. Hence, one should work to the manufacturer's directions or a textbook on the subject.

Steel.—The question of the type of steel to use is more or less a matter of individual requirements; both case-hardened and direct oil-hardened steel gears are largely used at the present day. The use of oil-hardening steel has the advantage of eliminating the element of chance distortion, always present to a greater or lesser degree with water quenched case-hardening steel. At the same time, case-hardened gears are perhaps as a general rule to be preferred. The strength of the alloy case-hardened

steel gears is nearly equal to that of direct oil-hardened material, assuming that in both cases steel of the appropriate composition has been used and the respective heat treatments have been properly carried out. In addition, the case-hardened gear often wears better and is more able to resist shock than the oil-hardened gear. The low-carbon alloy steels which are used for case-hardened gears have a carbon content of about 0.20. For oil-hardening gears, chrome vanadium, nickel chrome, nickel chrome molybdenum, and silico-manganese alloys are used, and with both high and low carbon contents. The former contains about 0.45 to 0.60 per cent. carbon and sufficient other hardening elements, so that by merely quenching the steel in oil from the specified temperature the surface hardening produced is adequate for ordinary wearing purposes. The effects of hardening depends upon the cross section; given adequate size it does not penetrate deeply into the gear, hence has the essential tough and strong core.

One point to bear in mind if production is to be facilitated is that of using as few grades of steel as possible, irrespective of the fact that there may be an incentive to select the steel to suit different shapes of gear and those for different purposes.

By judiciously selecting a few grades of steel which will show good average results the work of production can be materially simplified. On account of its great strength and toughness, and the fact that it hardens throughout, nickel chrome or a nickel chrome molybdenum straight-hardening steel is well adapted for the severe service that many gears are expected to withstand. Correctly heat-treated gears of this material do not often chip on the edges of the teeth, and they will stand up to the most severe usage in change-speed systems. They

tend to keep their shape better in hardening than gears of low-carbon case-hardening steel.

Those who are in favour of case-hardening steels contend that such gears show a greater resistance to wear on the tooth surface, whilst the steel costs less and the machining charges are about half those of oil-hardening steel. Moreover, the superior wearing qualities of the file-hard tooth surface of the case-hardened gear are certainly an asset in many engineering designs. At the same time, conditions often call for very small gears, in which case oil-hardening steel may be preferred.

Of alloy case-hardening steels, one of the grades most generally used is the nickel-alloy steel, having a nickel content varying from 1 to 5 per cent. The principal characteristics of this steel are a higher tensile strength than straight carbon steel, and a correspondingly higher strength after case-hardening. The carbon casing has a close bond with the core and is less liable to flake than ordinary machine steel. A 5 per cent. nickel case-hardening steel is used in automobile gear boxes; the straight carbon steels for case-hardening have a 0.15 to 0.25 carbon content. A lower carbon content is likely to result in a laminated case, which is apt to crack and flake under heavy pressure. Nickel alloy steel for carburising should not exceed over 0.20 per cent. carbon, as the nickel alloy has practically the same mass effect after hardening as an increase in carbon of 0.10 per cent. A 0.25 per cent. nickel alloy steel of a small section will, as a rule, harden throughout in much the same way as a straight hardening steel. It may be noted that in connection with large diameter gears when a hard tooth surface is required, it is usual to effect this by a surface-hardening process, of which the Shorter system, developed by David Brown & Sons Ltd., is one of the best known.

Gear Grinding.—Gear-tooth grinding is a process which steadily has come to the fore. As one may infer, it *can* be done by a formed grinding wheel, and an obvious requirement is a means for automatically truing the wheel as it wears, and a means of simultaneously lowering it to compensate for the reduction of the size of the wheel which the truing operation brings about. Given suitable wheels with a tough and well-bonded abrasive, fairly rapid work

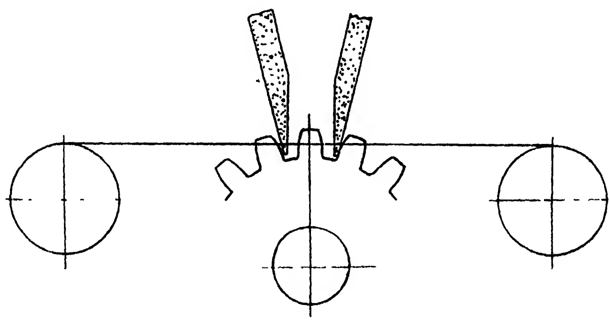


FIG. 423.—Grinding Gear Teeth

can be done by this method by grinding the wheel to within 0.001 to 0.002 in. of size, and later truing the wheel to the correct shape by means of mechanically guided diamonds; afterwards the teeth may all be finished without another truing operation. Briefly, the grinding wheel is attached to a carriage which is moved horizontally backwards and forwards for traversing the wheel across the gear teeth. The wheel is carried by a slide which may be arranged to move downward a slight amount at each return movement of the carriage. This lowering movement is but slight, being only sufficient

for the truing operation. The longitudinal movement of the wheel carriage is obtained by means of a cam drum motion beneath it, a roll on the underside of the carriage engaging a cam groove of suitable shape formed in the circumference of the drum.

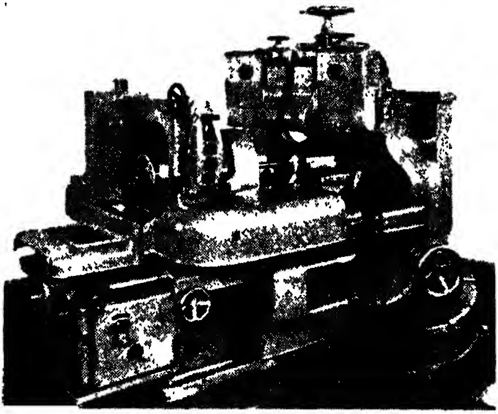


FIG. 424.—Maag Gear Grinding Machine.
(*By courtesy of Messrs Maag, Switzerland.*)

The alternative method of grinding gear teeth, now used to a greater extent, is that based upon the rack-and-pinion generating system as applied to the production of spur gears. The grinding wheel has an action analogous to that of a milling cutter, but in place of its being formed to the tooth gap it is a thin flat wheel, and its normal position is such that its face is inclined from the vertical to correspond to the pressure angle of the gear teeth. This is made clear by Fig. 423, which incidentally

shows the usual arrangement of double wheels as used, for instance, in the Maag grinder which is illustrated in Fig. 424.

Worm Gears

The worm gear is essentially a piece of mechanism for effecting considerable speed reduction with one pair of elements—the worm and the wheel. It must perforce do this at right angles, and with certain exceptions it is non-reversible, and although this may somewhat limit its application it provides an element of safety for such duties as lift operation. Its silence is one of the several points in its favour, for the rear axle drive of motor vehicles and its compactness renders it very useful for coupling up electric motors to pumps and other slow-speed machinery.

Outside of the power field worm gearing figures in a large variety of appliances, from a tiny wheel in a meter gear train to sluice operating mechanisms and steering gears, and it is altogether a very useful piece of mechanism. For relatively light duties it is simple to produce in the form of what is virtually a square-threaded screw engaging with a suitably formed spur gear, but for high-speed drives, to which it is being applied to an increasing extent, the mating elements have not only to be cut to extreme limits of accuracy, but they also have to be made of the best possible material.

So far as the worm itself is concerned, it is now usual to drop-forge it from nickel alloy steel in its rough toothed form, so as to ensure a proper flow of the material and to reduce the amount of metal to be removed as much as possible. The general procedure is one of milling and grinding the worm threads, the hobs for cutting the

wheel teeth being produced in a similar manner. In cutting the worm, the shaft having been secured in a headstock by a collet chuck and supported at the other end by a roller steady, it is given a spiral advancing motion past a rotary cutter in a universally adjustable head, the shaft having, of course, been turned, ground, faced to length, and re-centred for location purposes. During the movement of the rotary cutter a thread space is milled, but the feed is automatically tripped on completion. The blank is then returned and indexed for the next traverse. After this roughing operation and hardening of the essential parts, threads and/or splines are cut and the cylindrical surfaces ground, the tooth grinding being done in a special type of automatic machine. Finally the teeth are burnished, an operation regarded as essential for smooth, frictionless running.

Wheels: Importance of the Right Grade of Material.—The view in Fig. 425 shows the general form of a modern worm and wheel, and the latter, as might be inferred, is cast in the form of a ring, and centrifugal casting is now usually employed for this important operation. Under working conditions the surface layers are subjected mainly to compressive stress, but in the rim there is tension also. Therefore, in addition to having a high compressive strength, the material in a worm wheel must be resistant to fatigue on account of the alternating compressive and bending stresses. It should have a certain resistance to shock, high density, low coefficient of friction, and a low rate of wear under sliding friction. The demands, therefore, are high, and they are not met well by either manganese or aluminium bronze, which, while strong, wear badly. A tin base bronze is essential, and recent research has demonstrated the superiority of bronze about 88/11 copper-tin with

0.5 nickel content. By the addition of this small amount of nickel, assuming 0.3 phosphorus content, the impact value is considerably increased. This material has an

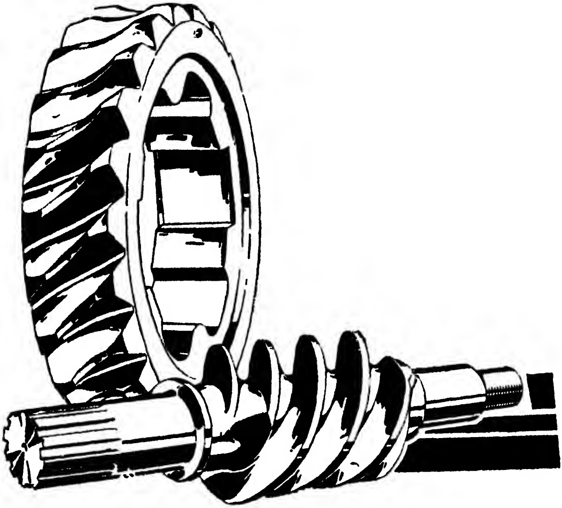


FIG. 425.—Worm and Wheel.

ultimate strength of 18 to 22 tons, with an elongation of about 11 per cent., a Brinell hardness of 95, and an average Izod impact value of 55 ft.-lbs. Rough-cast wheels of this material will bend nearly double without fracture. For larger sand-cast wheels the nickel content is about 1 per cent. to a 88.25/10.5 copper-tin mixture with 0.25 per cent. phosphorus. (See also B.S. 721.)

Worms and their Form. — There are essential differences in the form of worms. That shown in Fig. 425

is of the parallel-sided type, while there is another of the hollow encircling class, sometimes spoken of as the Hindley worm. It is used to a less extent than the former, but it is claimed by its sponsors to give a smoother and more even turning moment by reason of the uniform distribution of its load over a larger area of worm and wheel tooth profiles. On the other hand, the parallel-sided worm is a somewhat simpler manufacturing problem, and if it is correctly designed so as to maintain the essential oil film between the teeth of the worm and wheel it functions exceedingly well. Probably lubrication is the most vital factor, and present-day design is largely based on the assumption that the oil film is maintained on the principle of the Michell bearing. This, coupled with the high polish given to the worm, as previously mentioned, enables the gear to work at high speed with negligible wear and heat. Theoretically, the contact between a worm of the Hindley class and its wheel is line contact, but the elasticity of the material is considered as bringing about a condition of band contact, and it is vital that this be separated by an oil film. Unless the gear is correctly designed, the thickness of the oil film will depend upon the relative motion of the surfaces, and the unit pressure and the conditions will lead to imperfect lubrication. That the parallel worm can be designed to meet this condition is amply proved in practice, at the same time, in the case of the hollow worm with a suitably formed radius of curvature giving the maximum proximity of surface of the engaging teeth, the unit pressure will, admittedly, be reduced. Furthermore, the motion of the bands of contact will be such as will facilitate the building up of the oil film to give, as far as possible, absence of metal to metal contact.

Contact: Lubrication.—The load-carrying capacity of a worm depends upon a number of factors, though the most important of these undoubtedly centres around the lubrication of the surfaces in contact. Theoretically, the contact between the worm and the wheel is line contact,

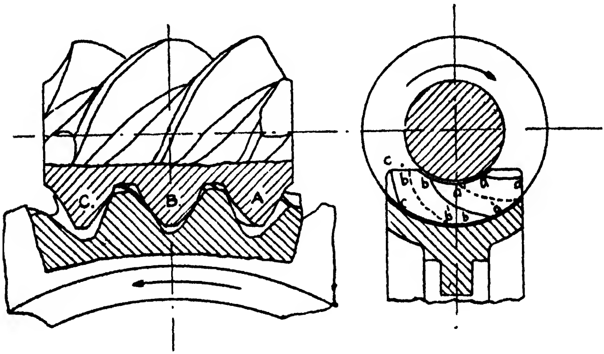


FIG. 426.—Conditions relating to Worm Wheel.

but as already pointed out the elasticity of the material brings about a condition of band contact, and it is this band contact which has to be separated by an oil film. Unless the gear and worm teeth are well designed, the thickness of the oil film will depend upon the relative motion of the surfaces and the unit pressure, and the conditions will lead to imperfect lubrication. On the other hand, by a suitably formed radius of curvature giving the maximum proximity of surface of the engaging teeth, the unit pressure will be reduced and, in addition, the motion of the bands of contact will be such as will facilitate the building up of the oil film. The result is that there is a virtual absence of metal to metal contact, which is obviously the most important condition.

Therein lies, too, a condition which underlies the

successful working of the Michell bearing, that is the wedge-shaped oil film. In order to bring this about in the case of a worm gear it has to be formed on the lines previously indicated in Fig. 426. Here, for the position shown, the load, according to experiments conducted by Messrs David Brown's, is carried by the three threads A, B, and C along the lines *a-a*, *b-b*, and *c-c* respectively. The lack of contact between the threads A and C and the worm is more apparent than real, and is due to the fact that *a-a* and *c-c* do not pass through the central plane of section. After a further 45° of rotation C passes out of action and the load is carried by the threads A and B along the lines *a′-a′* and *b′-b′*. These conditions are virtually ideal for efficient lubrication. In addition to the fact that there are always at least two teeth sharing the load, the line of contact makes a large and constant angle with the direction of sliding, whilst the lines of contact moving round with the worm give a high rolling velocity which makes for efficient lubrication and uniform wear. The velocity ratio remains constant, with resulting maximum efficiency and durability.

Points in Design.—Unlike spur gearing, there is no recognised international standard to which worm gears are yet designed. The current British standard, B.S. 721, is based upon the English module system although the diametral pitch is permissible. The root of the system consists in making both the P.D. of the wheel and the nominal P.D. of the worm integral multiples of the module, and this enables worms to be standardised, each being completely defined by the number of "starts" or threads, the module, and the number of modules in the P.D. All worms having the same number of starts and the same "diameter-module" are geometrically similar, and their respective dimensions are

directly proportional to the module. The lead angles are standardised, but in a manner which eliminates angular measurements from the calculations, pressure angles excepted.

This leads up to the following notation and formulas taken in conjunction with Fig. 427 :—

Module diameter $q=\tan \cot \lambda$.

Worm lead angle $\lambda=\tan \lambda=\dfrac{t}{q}$.

Module $M=\dfrac{2c}{t+q}$.

Centre distance $C=\frac{1}{2}(T+q)M$.

Nominal worm pitch diameter $=d=qM$.

Worm wheel pitch diameter $D=TM$.

d (actual) $=2\ (C-D)$.

Head of worm $L=\dfrac{22tM}{7}$.

Axial pitch of worm threads $p=\dfrac{22M}{7}$.

Worm thread addendum $a=\dfrac{1\cdot5\ Mq}{\text{[illegible]}}$.

Worm thread dedendum $b=0\cdot6a$.

Clearance $c=0\cdot1a$.

Wheel tooth throat addendum $A=0\cdot5a$.

Wheel tooth overall addendum $A'=0\cdot8a$.

Width of face $f=2\sqrt{a^2+ad}$.

Worm crest diameter $p=d+2a$.

Worm root diameter $i=d-1\cdot2a$.

Wheel throat diameter $O=D+a$.

Wheel overall diameter $P=D+1\cdot6a$

Root diameter $I=D-2\cdot2a$.

The system outlined is perfectly simple. The substitution of the fraction $\frac{22}{7}$ for π obviates any difficulty in setting change gears, the error of 0.001 in. in 2.5 in. being negligible in practice. A worm gear according to this (Messrs David Brown's) system, also B.S. 721, can be specified by its $t/q/m$ value plus the designation of its hand

R or L. For instance, 3R/8/0.25 designates a right-handed worm, with three threads and a pitch diameter of eight modules, the module being 0.25.

There is one point which ought to be made clear in

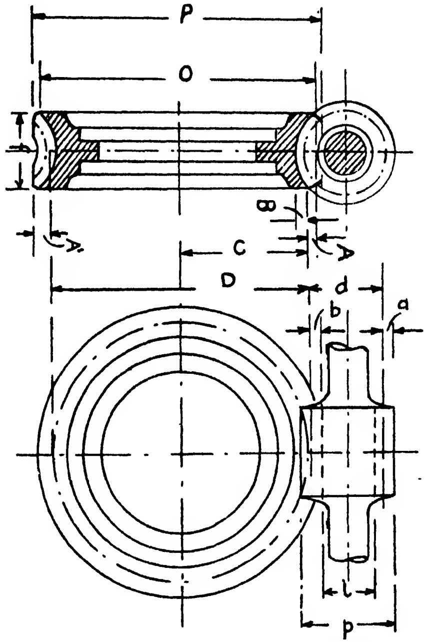


FIG 427.—Data relating to Worm Wheels.

connection with this module system, and that is it should be used in conjunction with a standard pressure angle of 20°. Now $14\frac{1}{2}°$ pressure angle may be satisfactory enough in the case of worms having a relatively small lead angle,

but when this is increased to, say, 35° difficulties arise. If, for instance, the lead angle is too small, there will be interference on the leaving side of the rim resulting in a loss of effective tooth area. Then it may be found that the worm and wheel will not assemble even though the wheel is cut by a hob which is an exact counterpart of the worm, rendering it necessary to screw the worm into the wheel axially. Such conditions lead to inefficiency. It is necessary, therefore, to design each worm of a series individually, with its own suitable thread contour laid out to give the best results for the selected combination of lead angle and diameter.

Production Methods: Cutting Worms.—In the production of a first-class worm gear selection of material plays an important part. The worms are, as a general rule, produced from forgings, sometimes with the thread rough formed in the forging process. The material must be absolutely free from any inclusions which would prevent a high polish being given to the finished thread surfaces. While the machines for production are usually specially built for the purpose to their own designs by the gear specialists, the general procedure is one of milling and grinding the worm threads, producing hobs in the same manner, and cutting the wheel teeth by such hobs. In the case of worms, the shaft having been secured in a headstock by a collet chuck and supported at the other end by a roller steady, it is given a spiral advancing motion past a rotary cutter in a universally adjustable head, the shaft, of course, having been turned, ground, faced to length, and recentred for location purposes. During the movement of the rotary cutter a thread space is milled, but the feed is automatically tripped on completion. The blank is then returned and indexed for the next traverse. This,

it will be understood, while only a roughing operation, has to be accurately done in order to leave a uniform grinding allowance and depth of case. The generation of the correct profile is effected by first turning a soft blank to the appropriate form and mounting on the cutter spindle. In place of the worm a tool with a single cutting edge is secured to the arbor carried between the work-heads, the tool being so disposed that when it is traversed in a spiral of the required lead it will sweep out a surface identical with that of the corresponding worm. The soft blank being rotated, the tool is wound slowly past it, with the result that it generates the correct cutter profile on the blank. This profile is then reproduced on the actual cutter. After the thread milling operation, such splines or keyways as are necessary are cut on the shaft, leaving the piece ready for heat treatment and case-hardening. Such parts as are to be left soft are plated, and, after hardening is completed, the screw threads are cut and the cylindrical surfaces are ground, when the piece is ready for thread grinding.

The grinding machine is fully automatic. The grinding wheel is held in a headstock in which the motor is mounted and it can be swivelled about two axes. The work, carried between centres, is given a helical motion determined by change gearing according to the lead of the threads. The position of the grinding head is first set according to the diameter of the worm being ground, and then the latter is set at the required angle for the first cut, and the machine being set in operation, one of the threads is ground during the first traverse of the table. At the end of the traverse a dog clutch is thrown over, reversing the direction of the travel of the table, the grinding headstock being simultaneously withdrawn through a friction clutch. On the return stroke the worm

is indexed, and when this stroke is completed the headstock is again fed up to the work and the cycle repeated. It will thus be seen that a fresh thread surface is ground at every traverse until one side of every thread has been ground the required amount, and on the worm being reversed, the remaining thread surfaces are finished in a similar manner. The object of this particular process is to distribute the feed uniformly over the threads and to avoid overheating. The thread surfaces are finished by a final burnishing to a mirror-like surface, which is essential in a first-class worm gear.

Machining the Worm Wheels.—The wheels, which are almost invariably of bronze, are cast in most foundries nowadays by a centrifugal process in order to ensure the necessary homogeneity of the material. The moulds are of steel, and a special refractory material is used in place of sand for the cores owing to its tendency to break down under centrifugal stress. The moulds are brought up to speed before pouring is commenced, and the metal is poured through a central hole in the top plate from crucibles suspended from a runway. The moulds are mounted on vertical gear-driven shafts and driven through cone clutches, brakes being provided for control. The blanks are first turned on special machines which finish them in two operations. One face, the bore, and half the rim are machined at the first setting, the other surfaces being finished after reversal of the blank in the three-jaw self-centring chuck. The next process is hobbing. The hob, Fig. 428, is to all intents and purposes a worm with the necessary gashes, and relieving to constitute it a cutting tool, and it is formed in the same way as the worms, so that the cutting of the worm wheel with accuracy is a relatively simple operation in which the wheel blank is mounted on a

suitable spindle and rotated at the same relative speed to the hob as its speed will be when it is mated with the worm.

But, in order to secure accuracy, it is necessary that every tooth on the hob shall cut in a different place after each revolution so that the cut will be distributed over the length of the hob cutting edges. As, however, the hob is fed across the face of the blank in a direction tangential to the pitch line it is necessary to incorporate

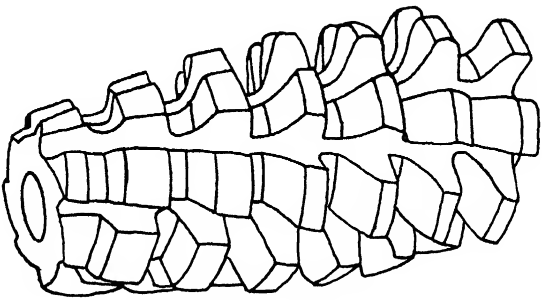


FIG. 428.--Taper Hob for Worm Gear Cutting.

a differential in the machine. This, mounted in the head, superimposes on the uniform rotation of the hob an additional rotary movement proportional to the advance of the hob.

Fig. 429 depicts the generation of the teeth of a worm wheel of the parallel type by tangential feed. It is this tangential feed which is largely instrumental in obtaining a fine finish to the teeth of the wheel. On most machines the cutter head is a self-contained independent unit having three distinct mechanisms all driven from the main driving shaft through the cutter driving wheels. First the drive is taken through two inclined shafts in line,

connected together at the centre by means of the aforementioned differential gear, and through a worm and worm wheel to the hob arbor. To obtain the tangential feed to the hob the drive is taken from the lower inclined shaft to a change-feed gear box, and thence through another worm and wheel and a pair of bevel gears to the lead screw, while the third motion is an additional rotary

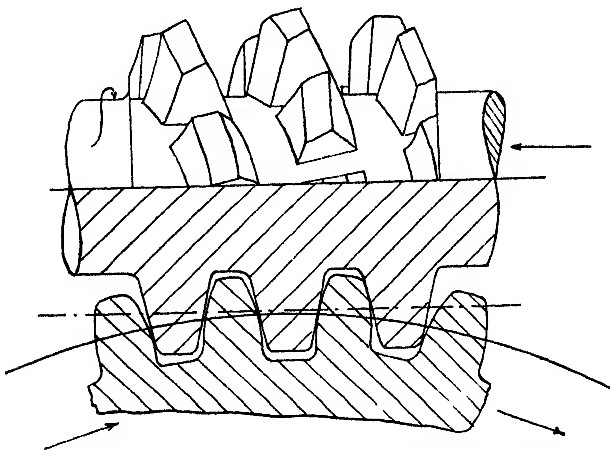


FIG. 429.—Cutting Worm Wheel, using a Parallel Hob.

movement of the hob to compensate for its longitudinal travel. In order to effect this the drive is taken from the lead screw through change gears to a worm and wheel, the latter carrying a cross piece on which are mounted the bevels forming part of the differential gear at the centre of the inclined shafts, this superimposing the differential motion on the hob arbor drive.

After the hob has travelled the required distance across the face of the blank the differential automatically

becomes disengaged. The hob, meanwhile, is being fed radially inwards, but at a variably decreasing rate, so that the maximum rate of feed shall obtain when the area of the cut is at the minimum. This ensures a constant weight of material being removed the whole time. While the bulk of the metal is therefore removed by in-feed, the final finish to a high polish can be given by the all-important tangential feed, which incidentally is not possible in the case of hollow worms.

In this case the cutters are of the inserted tooth type. This cutter is fitted to the driving spindle sleeve, the drive being through hardened spiral bevel gearing mounted in a large cast-iron trunnion. This trunnion can be turned through 360° and can be accurately set to 5′ of angle. The drive, from the motor to the cutter spindle bevels, is through double helical gearing with a means of obtaining variable and reduced speed when it is required to generate the hobs for cutting the wheels. The whole of the cutter driving mechanism is mounted on a saddle which can move backwards and forwards to a limited degree to cover the largest pitch depth required, while the same saddle revolves in a base saddle which can be set to the correct centre distance by a vernier adjustment.

Testing Gears

Gear production to-day has reached a fine art. In the automobile field there is an enormous production of gears, usually comparatively light, but which have to stand up to extremely hard usage. That they can do so is due, first, to the use of suitably heat-treated alloy steels, and secondly, to accurate cutting on modern machines. Then there are the exacting requirements

of electric traction, and the reduction gears on turbine sets which have to be met by larger gears, usually of the double helical class, and the same applies to electric winders, etc., and the stock sets of reduction gears now much employed.

Testing is an important part of the production of modern high efficiency gearing, and there is a good deal of this equipment now available, often made by the gear specialists themselves originally for their own purpose. Some of it, of course, can be classified as laboratory equipment: delicate instruments which can measure to very fine limits but which have to be taken special care of, such as being kept at an even temperature.

Of machines suitable for workshop and tool-room use the Maag gear tester for spur gears is simple and robust. Shown in Fig. 430, there are two slides *a* and *b*, the former being adjustable by means of the spindle *c*, which can be locked in any position by nut *d*. The vernier N moves over the scale S and enables the position of the slide to be set to $\frac{4}{10000}$ in. On a taper bore in the table is carried an interchangeable mandrel *e* on which one of the gears being tested is mounted. The slide *b* carrying the mandrel *f* runs on the bed of the tester in a ball-bearing guide. This slide can be secured by the peg *g* so that the vernier gives a reading on the scale indicating the centre distance between *e* and *f*. On withdrawing the peg *g*, the spring *h* presses the slide *b* out of its zero position so that with the centre distance reduced the indicator *i* registers the movement of the slide until the gears are in mesh without any play.

Play is understood as the maximum clearance between the tooth flanks of two engaging teeth measured along the line of action when the gears are set at the predetermined centre distance C. If *n* and N represent the

number of teeth in pinion and gear, and DP the diametral pitch, $C = \frac{n+N}{2DP}$. The play can be determined in two

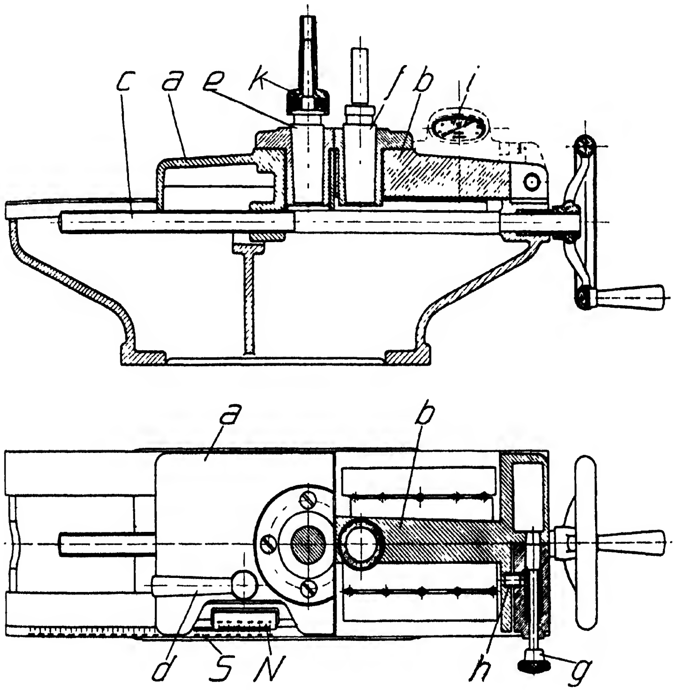


FIG. 430.—Maag Gear Tester.

ways, first, by setting up the gear and setting the scale S to the centre distance C and measuring the play between the teeth by means of a feeler gauge, or the centre

distance can be reduced until both gears are in engagement without play and the reading taken from the scale. From the distance D between the correct centre distance and the reading of the scale S the play F is calculated from the expression $F = kD$ where k is a constant equal to $\frac{\text{Sin } 2a}{\text{Cos } a}$, where a is the pressure angle.

For testing concentricity the large gear should be mounted on the slide *a* and the smaller one on *b*. The bolt is then withdrawn and the centre distance reduced until the indicator pointer is only slightly moved; the slide *a* is then locked in position. If the gear on the fixed slide is turned by hand, any eccentricity of the teeth on either gear will show on the indicator pointer by causing a movement of the free slide.

A Machine of General Utility.—The instrument shown in Fig. 431, by David Brown, has a more general utility. It can deal with either spur or helical gears and can be used with worms. It records directly on a dial indicator, as will be seen, which indicates deviations of $\frac{1}{10000}$ from the true involute, and the tester is so constructed that this accuracy is consistently maintained. It is, too, exceedingly simple and strong. The gear being tested is mounted on an arbor and concentric with a "base disc" whose diameter equals that of the base circle diameter of the gear. The ground periphery of this base disc makes contact with a hardened and ground reference face B over which it rolls, while the under face rests on and slides over the surface of the base plate. By means of the rod set parallel to the face of B and the base disc being held between B and C, movement of C in either direction causes the base disc to roll along the surface of B without any slip. Sufficient compression between the surfaces is applied through the slide D, with its two

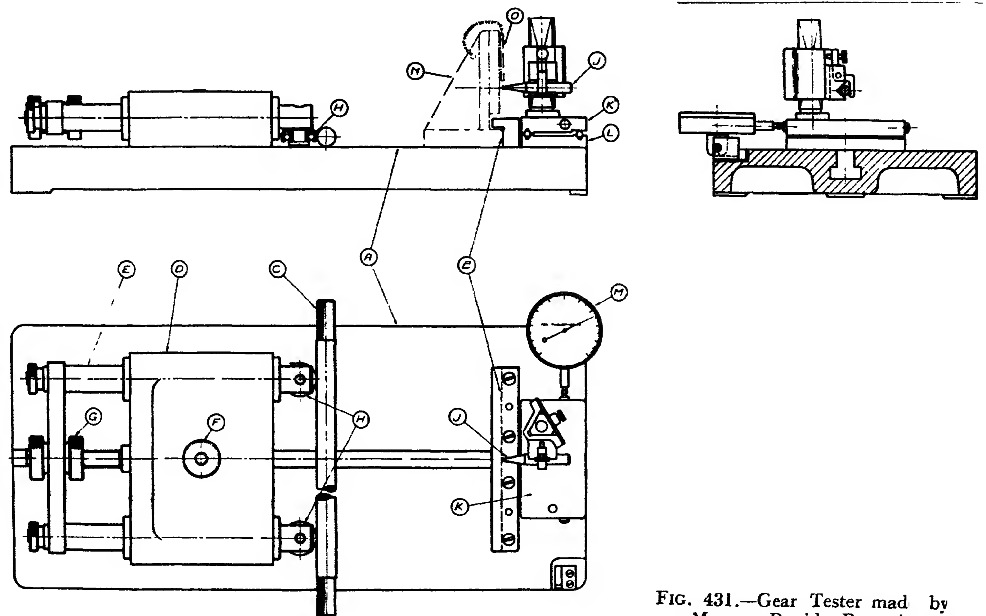


FIG. 431.—Gear Tester mad by Messrs David Brown's of Huddersfield.

compression plungers E having ball-bearings H, which allows the rod to move laterally, and in doing so to rotate the base disc. Slide D can be locked in any required position by means of nut F, while by means of nut G correct compression giving the final adjustment is made.

When the gear is rolled past the point of the stylus J it indicates any departure from the true involute on dial M and, the end of the stylus being conical in form, ensures that the gauging point shall always lie in the plane of reference B, whilst by slightly rotating it a new point on the gauging knife edge can be brought into action should any wear have occurred.

Chordal Thickness: Defects of the Vernier Method.—The tooth vernier, Fig. 432, is so familiar as to call for no comment. It makes possible the determination of the chordal tooth thickness at a certain depth from the outside diameter and, further, to compare the thickness of all the teeth at the same depth. Although the teeth may be of equal thickness, the tooth spaces may be unequal; furthermore, as the teeth are measured from the outside diameter and the gear itself is subsequently positioned from the bore for running purposes, any eccentricity of the outside diameter with relation to the bore will give false vernier readings. In order to provide means of measuring the outside diameter independently a ground cylindrical mandrel can be positioned in a tooth space, and the gear then being rotated with it and the mandrel passed beneath a dial test indicator, the movement of the pointer can be noted and the process repeated for the other teeth. These readings are more accurate and independent of the outside diameter, but do not give any indication of accuracy of pitch. By means of two mandrels in adjacent tooth spaces, with one clamped to an arm carrying a dial test

indicator and swung past the other, the centre distances between two adjacent tooth spaces can be measured to $\frac{1}{100}$ mm.; but for small pitches an instrument is now made by the Maag Gear Co. which determines the distance from one flank to the next successive flank which, although the tooth spacing may be equal, may quite

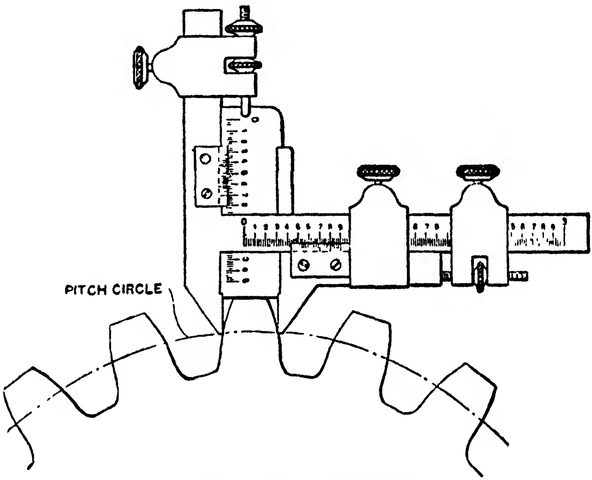


FIG. 432.—Gear Tooth Vernier.

possibly be unequal. It is important that they should be equal, because when gears are in engagement it is only the driving profiles which are in contact.

Referring now to the diagram in Fig. 433, measurements taken by a tooth vernier equal $2 \tan 15° \times h$, while the error, according to the method described, is equal to

$$\left(\frac{CP \times R - h}{R}\right) - CP$$

where CP is the circular pitch and R the radius at which

measurement is taken. Or assuming the number of teeth to be 60, the module 7, and $h = 0.1$ mm., the error, according to the tooth vernier, equals $2 \times 0.2679 \times 0.1 = 0.053$ mm., while according to the method outlined the error is equal to

$$\frac{(22 \times 420 + 0{\cdot}1)}{420} - 22 = 0{\cdot}004 \text{ mm.}$$

Thus a gear which is in reality absolutely true as regards pitch may show a relatively large error when tested by a tooth vernier.

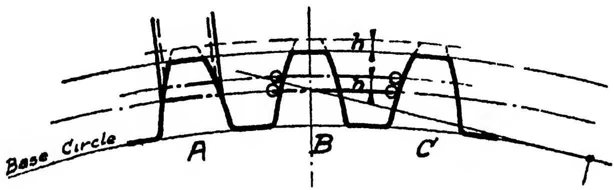


FIG. 433.—Measuring Gear Teeth.

Profile Testing.—The instrument shown in Fig. 434 is a simple one for profile testing. The gear is fixed on the spindle *a* of the instrument, which also carries a disc *b*, which is ground to the base circle diameter of the gear. There is a slide *c* having a straight edge *d* on one side. On the top of the slide is the pivoted lever *e*, one end of which is lipped, as shown at *f*, while the other end is connected to the roller *g* in such a manner that any motion of the lever is transmitted to the roller, the spring *h* keeping it in tension. To this roller is fixed the pointer *j* carrying a pen. The diagram paper *k* is fixed on a slide which remains stationary while the curve profile *l* is being taken, though it may be moved on a small guide parallel to the table slide to enable a zero line to be drawn by using the pencil holder *n*. If the slide *c* with straight

edge *d* is moved the base circle *b* which is pressed against the straight edge will be rotated a similar distance. Each point on the straight edge, which is tangential to the base circle, describes an involute curve similar to the base circle, as does the lipped pointer *f* which is situated

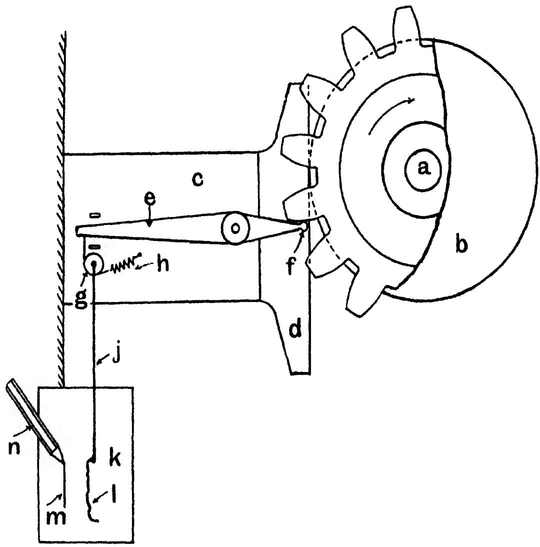


FIG. 434.—Profile Testing of Gear Teeth.

exactly above the straight edge in contact with the tooth profile. Any variation in the profile causes movement of the pointer *j* which is transferred by the pen to the diagram paper. The curve *l* is that for the whole profile, the length of the curve being equal to the total movement of the slide *c*. If the profile is absolutely correct the curve *l* is a straight line parallel to the zero line *m*.

CHAPTER XX

BORING AND SLOTTING MACHINES

BORING machines, as with all other types of modern machine tools, are constructed in a great variety of forms and sizes. They can roughly be divided into horizontal machines, where the work is stationary and the tool moves, and vertical machines, in which the work rotates. In appearance, the horizontal machine partly resembles the modern lathe, the boring head carrying the boring bar or boring tool, the work being secured to the table of the machine. The great advantage the boring machine has over the lathe lies in the fact that the table permits components too large to be held in the chuck or on the face plate to be effectively clamped in position.

A modern type of horizontal machine is illustrated at Fig. 435. This particular class of machine has an individual motor. Twelve different speeds can be obtained by means of the speed box which is provided with sliding gears and clutches, operated by levers in front of the machine.

The Bed is of heavy box section, strongly reinforced by internal ribs. A narrow guide is incorporated in the design, and this is in close proximity to the lead screw. The guideways are covered for the whole of their length, also the lead screw, and are thereby completely protected from damage by cuttings. A wide channel is provided for the reception of chips and coolant, and a chute conducts the chips to the rear of the machine. The bed is exceptionally wide, affording ample support to the saddle and reducing overhang of the tables to a minimum.

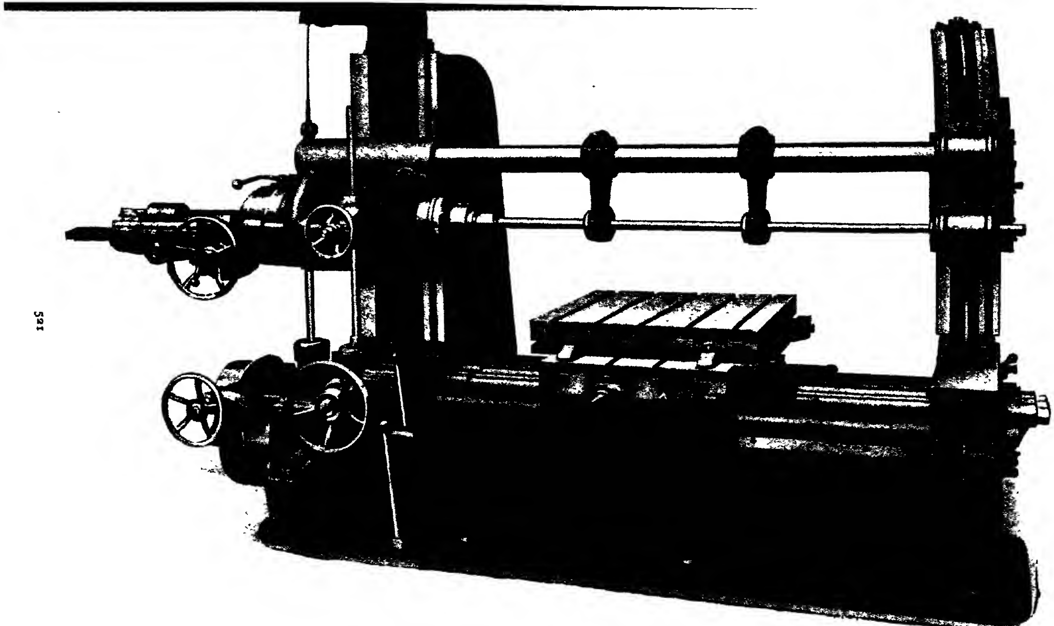


FIG. 435.—Horizontal Boring Machine.
(*By courtesy of G. Richards & Co. Ltd., Manchester.*)

The general specification of the machine featuring at Fig. 435 is as follows :—

SPECIFICATIONS FOR NOS. 2 AND 2A SIZES
"HB" TYPE HORIZONTAL BORING MACHINES

	Dimensions.	
	No. 2 English.	No. 2A English.
SPINDLE—		
Diameter	$2\frac{5}{8}$ in.	3 in.
Traverse	20 in.	24 in.
Diameter with bore	10 in.	12 in.
Bored morse taper	No. 4	No. 5
VERTICAL ADJUSTMENT—		
Maximum distance centre spindle to revolving table	24 in.	30 in.
Maximum distance centre of spindle to main table	28 in.	34 in.
SPEEDS—		
Number	12	12
Range—		
Machine with plain bearings	16 to 400 r.p.m.	16 to 400 r.p.m.
Machine with pre-loaded roller bearings	30 to 750 r.p.m.	30 to 750 r.p.m.
FEEDS—		
Boring and drilling—		
Number	24	24
Range per revolution	·001 to ·324 in.	·001 to ·324 in
Milling—		
Number	72	72
Range per minute	·096 to 22 in.	·096 to 22 in.
BED—		
Width over slides	25 in.	25 in.
Maximum distance between spindle nose and boring stay	5 ft. 0 in.	7 ft. 0 in.
TABLES—		
Revolving table	30 × 30 in.	36 × 36 in.
Main table	39 × 24 in.	48 × 30 in.
Traverse, longitudinal	30 in.	48 in.
Traverse, transverse	28 in.	36 in.
SPEED OF DRIVING PULLEY		
Machine with plain bearings	500 r.p.m.	500 r.p.m.
Machine with pre-loaded roller bearings	750 r.p.m.	750 r.p.m.
POWER TO DRIVE—		
Horse power required	$7\frac{1}{2}$	$7\frac{1}{2}$

The Upright is also a heavy closed box casting. It is securely bolted to the bed, and has extra wide and accurately ground bearing surfaces for the spindle frame. A taper gib is provided to compensate for any wear that may take place on the spindle frame.

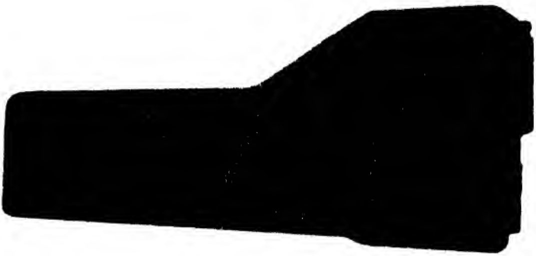


FIG. 436.—Underside of Bed, showing the Ribbed Construction.

Tables.—The machine is provided with two tables, viz., the lower or main table and the upper or detachable turntable. The centre pin upon which the upper table turns can be raised and lowered by a small lever from the front of the main table, and by means of which heavy loads can be lifted and moved round with ease. An additional advantage of this application is that owing to its sensitiveness our patent squaring lock ensures perfect alignment. This patented device provides a wedge which fits the whole length of the table, the wedge being actuated by lever pinion and rack as shown in Fig. 437.

The Saddle on which the main table slides transversely is of substantial proportions and of such a length as to afford ample support to the table in all positions. Furthermore, the cross traverse slide is of the narrow guide type.

The Spindle and its Sleeve are of high-grade carbon steel, ground all over. The spindle sleeve is lapped into

and runs in two parallel phosphor-bronze bearings, one at the front and the other at the rear. The spindle does not rotate within the sleeve, having merely a sliding movement axially through it, and to facilitate which the sleeve is provided with two long cylindrical bearings

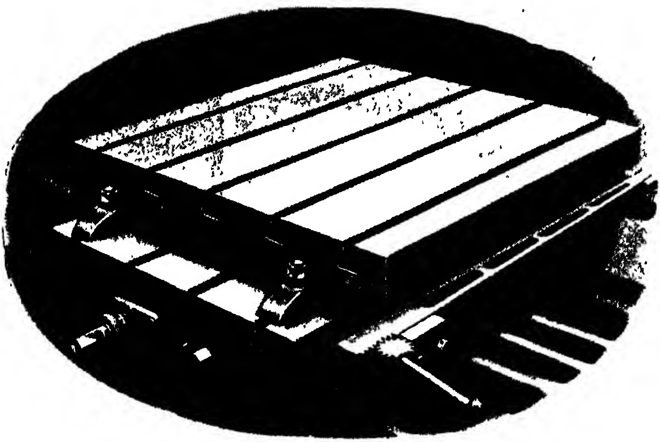


FIG. 437.—Table on a Richards Boring Machine.

of phosphor-bronze. The spindle nose is bored Morse taper, while for milling and facing the spindle may be readily tightened in the sleeve. Axial pressure is taken up by ball-thrust bearings. Fine adjustment to the spindle horizontally is provided through a conveniently placed handwheel with graduations of .001 in.

Patent Overarm Brace.—The spindle frame on all these machines can be so arranged that Patent Overarm

Brace can be fitted at any time. The spindle frame is counterbalanced by weight inside the upright.

Feeds and Speeds.—Ample feeds and speeds are provided, as indicated in the specifications, and particular attention is drawn to the wide range of milling feeds available, as distinct from boring and drilling feeds. Interlocking levers prevent any possibility of the feeds being engaged in different directions at the same time.

Slipping Clutch of improved friction type is provided for the protection of the feeds and rapid power traverse. This can be readily adjusted to suit the maximum load to be dealt with.

Rapid Power Traverse is provided in all directions, *i.e.*, to the table longitudinally and transversely; to the spindle frame vertically; and to the spindle horizontally. It is independent of and acts in the opposite direction to the adjusted feed, is engaged by a single lever, and automatically stops on releasing the lever. It is impossible for the automatic feed and rapid power traverse to be engaged simultaneously.

The Boring Stay is very rigid and capable of carrying boring bars of large diameter. It is mounted on a saddle which can be traversed along the bed by pinion and detachable handle. When not in use the stay can be removed and the saddle utilised for supporting long or overhanging work. The bearing block has simultaneous vertical movement with the spindle through bevel gears and shaft, a safety device being incorporated to prevent any misuse by the operator. Fine adjustment is also provided to ensure the bearing block being accurately reset in alignment with the spindle. The bearing has a hinged cap, the joint of which is placed at an angle. By this construction the bar does not require its full length

for insertion, and furthermore, it is actually supported by the stay whilst the cap is being secured. When required,

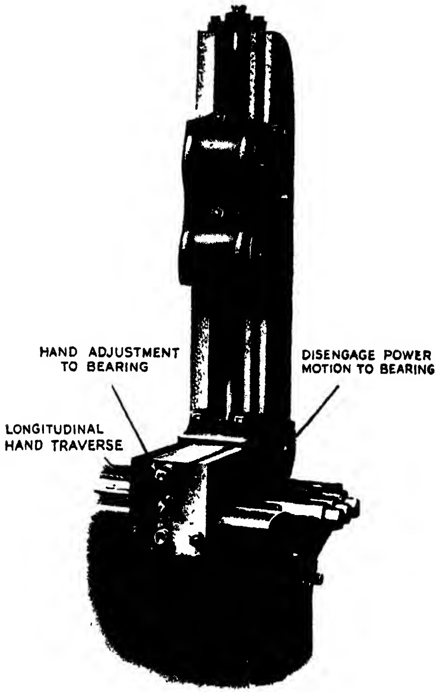


FIG. 438.—Boring Stay.

the power elevating motion to the stay bearing can be disconnected by lever at the foot of the stay and the bearing adjusted vertically by hand.

Gearing.—All gears, worms, racks, etc., are in steel, the transmission gearing being of nickel chrome steel

hardened and ground. Ball bearings have been liberally used throughout the transmission.

Lubrication.—Forced lubrication is provided to the main spindle bearings by means of a plunger pump contained in the spindle frame, and the amount of oil supplied to the bearings can be regulated according to the speed of the spindle. Splash lubrication is provided in the change-speed gear box, an oil level indicator being fitted to indicate when there is sufficient oil in the reservoir—the latter being part of the gear box itself. Other bearings are supplied with oil under hand pressure by oil gun, the special nipples being conveniently grouped.

Drive.—The machine is fitted with speed gear box, driven by constant-speed electric motor. The motor is mounted on self-contained baseplate attached to the gear box, and the transmission is by totally enclosed vee-ropes.

A constant-speed motor running at approximately 950 r.p.m. is recommended.

Rules and Vernier Scales.—For convenience in accurately recording adjustments to the spindle and boring stay block vertically and to the table transversely, vernier rules can be fitted at extra cost. These can be graduated in either English or metric dimensions, and magnifying glasses are also provided to facilitate their reading.

Facing Head.—When required a detachable facing head can be supplied for mounting on the spindle. This facing head can be supplied to suit a variety of work.

Foundation.—No special foundation is required, apart from a 4 in. diameter pit to accommodate the vertical driving shaft, providing a good solid floor is available. Levelling-up screws are provided, and these should rest on steel plates about 6 in. square. After being levelled up, the bed should be grouted with cement.

Tools and Equipment

Boring Bars.—These bars are of high-quality steel and can be supplied in varying diameters and lengths.

Boring bars, particularly when being used for heavy duty, have great stresses thrown upon the driving end, and to distribute this load a slot is provided across the spindle end into which fits the shoulder formed on the end of the bar.

The bars are provided with slots to receive boring cutters, or with keyway to receive boring heads.

Adjustable High-Speed Boring Head.—This boring head is very convenient for mounting in the end of the traversing spindle. It is suitable for the accurate boring of very small holes up to its full capacity, and adjustment to suit the diameter of hole to be bored is obtained from a micrometer screw reading to .001 in. The tool can be locked in any position and great rigidity is ensured.

Boring Head.—Fig. 441 illustrates one type of cast-steel boring head used in conjunction with the boring bar.

Milling.—These machines are admirably adapted for performing a wide variety of milling operations, as will be seen from the illustrations reproduced herewith. The spindle of the machine is provided with a flange to receive large cutters, whilst smaller cutters are mounted in the spindle end.

Large Milling Cutters for Bolting to Spindle Flange.—These cutters have solid flange and are spigoted and bolted direct on the spindle flange as shown in Fig. 442. They can be supplied in a variety of sizes to suit the spindle flange.

FIG. 439.—A Set of Boring Bars.

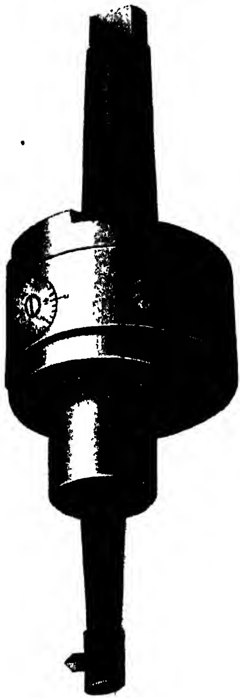


FIG. ·Head with S rd Bar

FIG. 441.—Steel Boring Head.

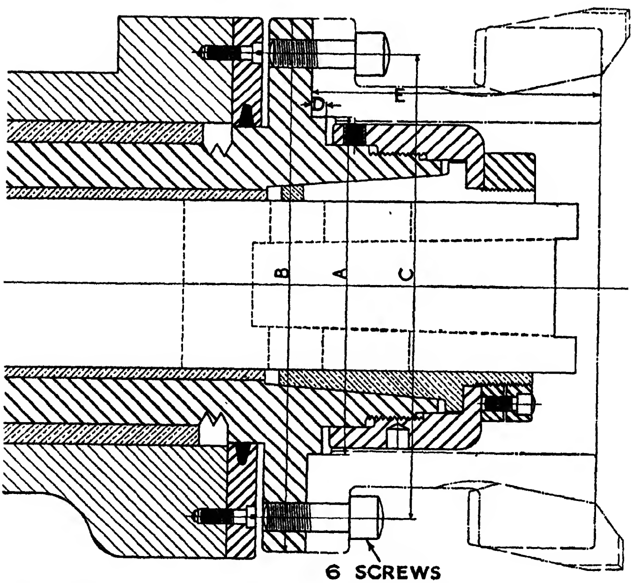


FIG. 442.—Facing Cutter attached to the Boring Machine Spindle.

Fig. 443 shows a face milling cutter mounted on arbor fitting directly into the spindle nose and driven by means of the cross slot in the spindle end and the tongue on the arbor. It will be observed that the spindle is supported

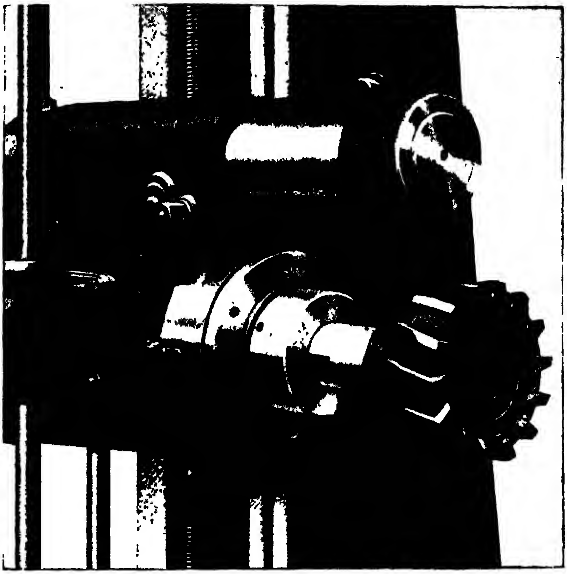


FIG. 443.—Facing Cutter on Richards Boring Machine.

by the patent overarm brace, which ensures rigidity under heavy cuts. This method is particularly valuable if the cutter is required to work with the spindle extended.

Spindle Support Socket.—In cases where it is not possible or convenient to utilise the overarm brace to

support the spindle when required to be extended, a socket can be supplied which is bolted to the spindle flange. This is clearly shown in Fig. 444.

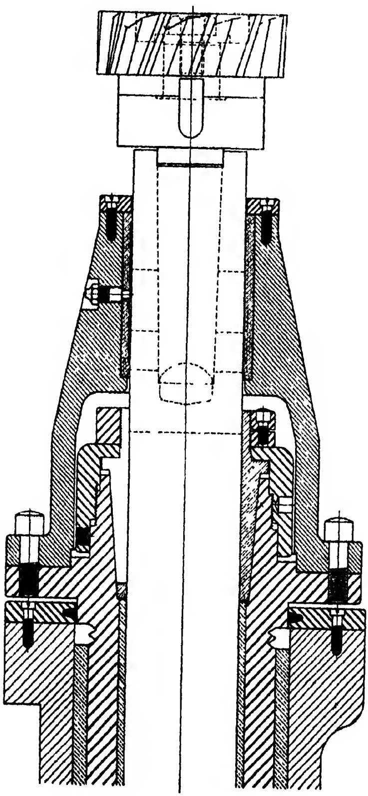


FIG. 444.—Cross-section showing one Method of Holding a Facing Cutter in a Richard Boring Machine Spindle.

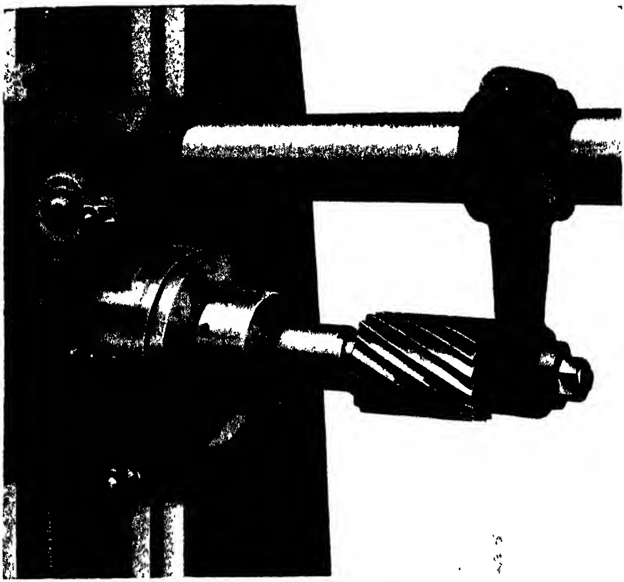


FIG. 445.—Cylindrical Milling Cutter held on a Boring Machine Spindle.

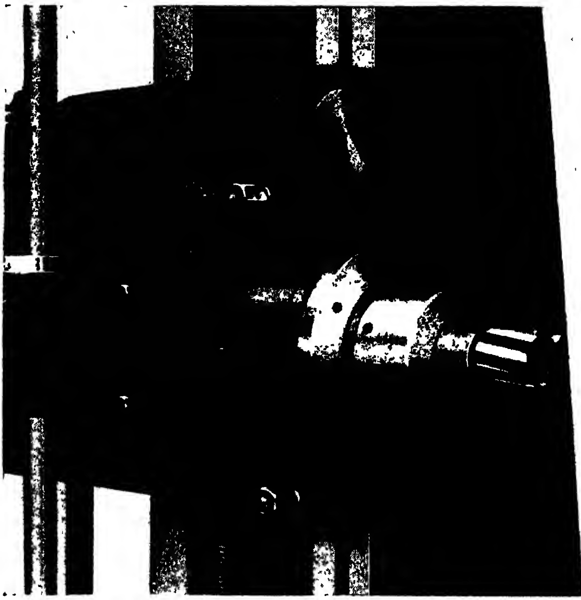


FIG. 446.—End Milling Cutter held in a Boring Machine Spindle.

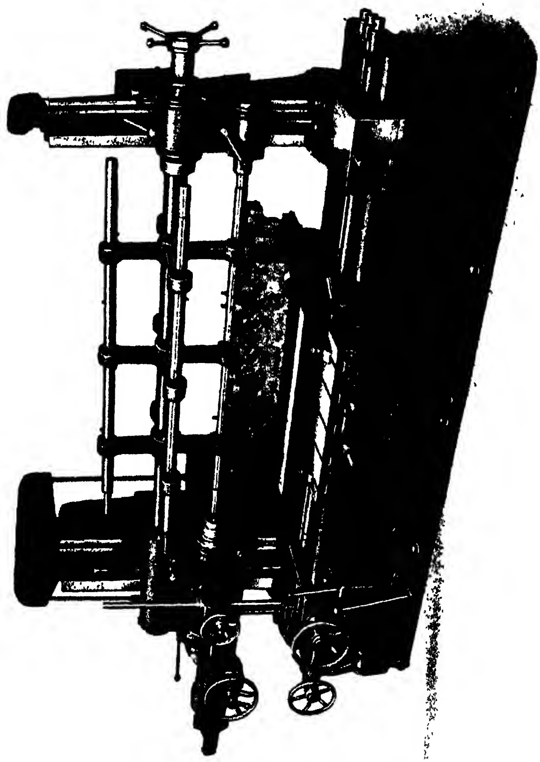


FIG. 447.—Overarm Brace carrying four Boring Bars machining an Aero Engine Crankcase.

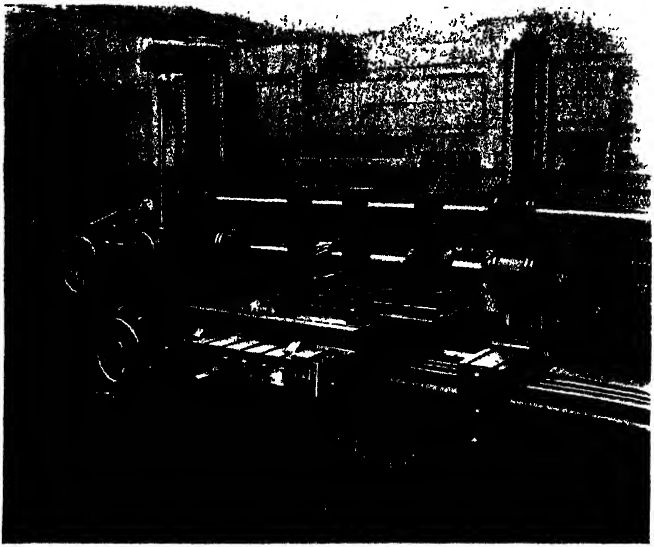


FIG. 448.—Gang Milling on a Boring Machine.

Vertical Boring Machines

There are a number of shops in which a vertical boring machine, or as it is often termed, a vertical turret lathe, can be profitably employed, and a great deal of work which can only be machined on the lathe with difficulty, owing to the time and trouble involved in setting up, can be done on this type of machine. In its duplex form, as shown in Fig. 451, it is valuable for the rapid production of a wide range of work. The machine (by Webster & Bennett Ltd., of Coventry) illustrated is made in two sizes, 36 and 48 in., with chucks to suit. The gear changes, as well as the starting and stopping of the machine, are

effected by the movement of the handles in front of the machine—one for each table. The whole of the driving gears have machine-cut teeth, and special provisions are made for the efficient lubrication of the driving shaft bearings, which are bushed with phosphor bronze. The

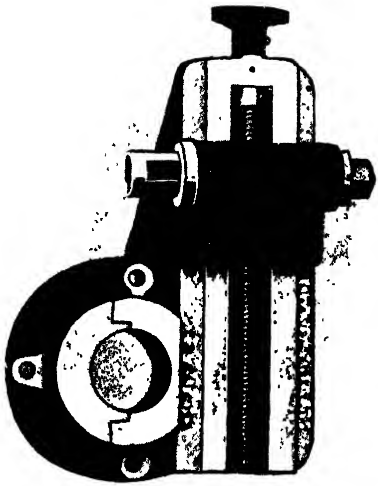


FIG. 449.—Star Feed Facing Attachment.

top bearings of the hollow spindles are conical in form and run in adjustable taper bushes. Being driven by spur gears, there is no tendency on the part of the table to lift when taking heavy cuts.

The automatic feeds of the turrets are entirely independent. The drive is from an individual motor and thence to the gear box. A good range of feeds are provided to each turret in the horizontal and vertical

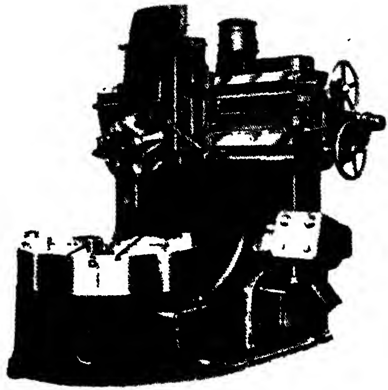


FIG. 450.—Vertical Turret Lathe and Boring Machine.

(*By courtesy of Messrs Webster & Bennett Ltd., Coventry.*)

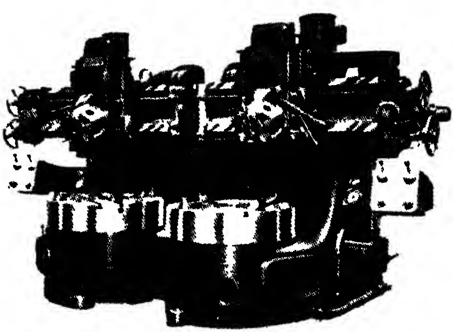


FIG. 451.—Duplex Vertical Turret Lathe or Boring Machine.

(*By courtesy of Messrs Webster & Bennett Ltd., Coventry.*)

directions, the gear changes being effected by the movement of a small lever operating a sliding key in the gear box, an index dial indicating the various rates of feed. Quick hand adjustments are also provided to the horizontal and vertical movements of the turret.

Independent and easily adjustable automatic trips are provided for the vertical and horizontal feeds of each turret, which can be set to trip the automatic feed at any predetermined point of the traverse. The automatic feed can also be disengaged by hand at any point without stopping the machine.

The turrets are bored to receive five tools, the latter being secured in position by steel clamping bolts. The turrets can be rigidly clamped to the saddle, eliminating vibration and ensuring rigidity while the tools are cutting, and provision is made for locating the turrets exactly central with the tables for boring or drilling operations. The turret slides are counterbalanced, and screw-operated adjusting strips are fitted to both the saddles and cross slide to compensate for wear.

The base and upright are box section castings designed and proportioned to ensure strength and rigidity to the tables and cross slide. Removable covers in the base facilitate the inspection of the driving mechanism.

Taper Turning

When it is necessary to machine on the boring mill a conical surface which has such a large included angle that the tool bar cannot be swivelled far enough to permit turning by the usual method, the combined vertical and horizontal feed are sometimes used to obtain the required taper. Suppose a conical casting is to be turned to an angle α of 30° (see Fig. 452), and that the tool head of the

boring mill feeds horizontally $\frac{1}{4}$ in. per turn of the screw, and has a vertical movement of $\frac{3}{16}$ in. per turn of the vertical feed shaft. If the two feeds are used simultaneously with the tool bar at right angles to the table; the tool will move a distance *h* of 8 in., while it moves downwards a distance of 6 in., thus turning the surface to an angle β. This angle β is greater than the required angle α, but if the tool bar is swivelled to an angle γ, the tool, as it moves downwards, will be advanced horizontally in addition to

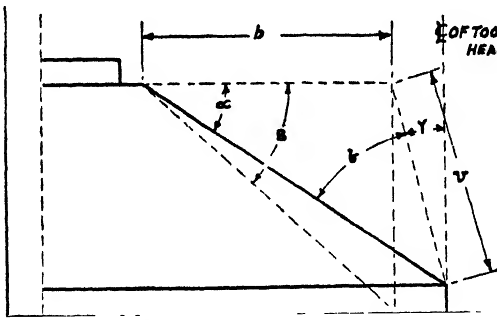


FIG. 452.—Diagram for Taper Turning.

the regular horizontal feeding movement. Hence, if the tool bar is set over to the proper angle γ, the surface can be turned to an angle α.

The problem, then, is to determine what the angle γ should be for turning to a given angle α. Angle γ can be calculated as follows: $\text{Sin } b = \dfrac{\sin \alpha \times h}{v}$, in which *h* represents the rate of horizontal feed and *v* the rate of vertical feed. Having angles α and *b*, the desired angle γ is obtained by subtracting the sum of the former angles

from 90°. To illustrate (using the values given in the foregoing), the sine of 30° is 0.5; then, $\sin b = \frac{0.5 \times \frac{1}{4}}{\frac{3}{16}} = 0.6666$.

Hence, angle $b = 41°48'$ and $\gamma = 90° - (30° + 41°48') = 18°12'$. If angle α were greater than angle β obtained from the combined feeds with the tool bar in the vertical position, it would be necessary to swing the lower end of the bar to the left rather than to the right of the vertical plane; that is, the lower end of the bar would be inclined to the left of the vertical an amount equal to the sum of the angles α and b subtracted from 90°.

Boring and Turning Mill.—Fig. 450 illustrates a single type of boring mill which is made in three sizes, 36, 48, and 60 in. Here again the machine has its own individual motor and the drive is through a gear box. The table rests on a large conical seating, and the centre spindle runs in parallel bearings.

RULES FOR FINDING TAPER.

Given	To Find	Rule.
The taper per inch	The taper per foot	Multiply the taper per inch by 12.
The taper per foot	The taper per inch	Divide the taper per foot by 12.
End diameters and length of taper in inches	The taper per foot	Subtract small diameters from large; divide by length of taper, and multiply quotient by 12.
The taper per foot	Amount of taper in a certain length given in inches	Divide taper per foot by 12; multiply by given length of tapered part.
Small diameter and length of taper in inches, and taper per foot	Diameter at large end in inches	Divide taper per foot by 12; multiply by length of taper, and add result to small diameter.
Large diameter and length of taper in inches, and taper per foot	Diameter at small end in inches	Divide taper per foot by 12; multiply by length of taper, and subtract result from large diameter.
The taper per foot and two diameters in inches	Distance between two given diameters in inches	Subtract small diameter from large; divide remainder by taper per foot, and multiply quotient by 12.

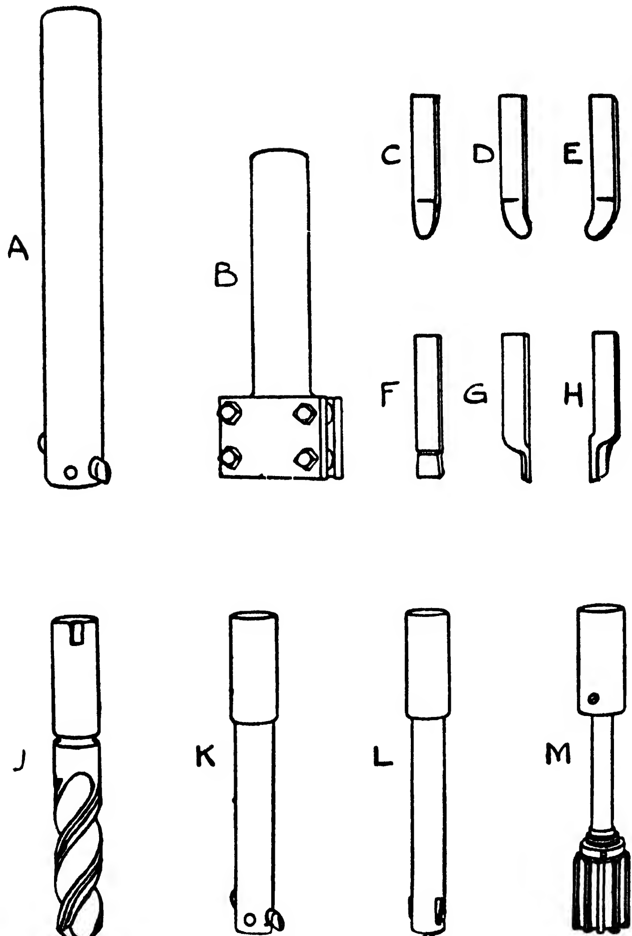


FIG. 453.—Boring Mill Tools.

Boring Mill Tools

A set of standard boring mill tools is shown in Fig. 453. The various tools are:—

A. Boring bar with single cutter	Suitable for boring mill without turret.
B. Holder for turning tools	
C. Roughing tool, straight	
D. Roughing tool, right hand	Suitable for boring mill with or without turret.
E. Roughing tool, left hand	
F. Broad finishing tool	
G. Knife tool, right hand	
H. Knife tool, left hand	
J. Three-grooved drill for cored holes	
K. Rough boring bar with single cutter	Suitable for boring mill with turret only.
L. Finish boring bar with double cutter	
M. Adjustable reamer with floating holder	
B. Holder for turning tools	

Slotting Machines

The slotting machine illustrated in Fig. 454 is of modern design and has been constructed to perform a great variety of work. The machine shown is for precision work as found in toolrooms dealing with a wide range of

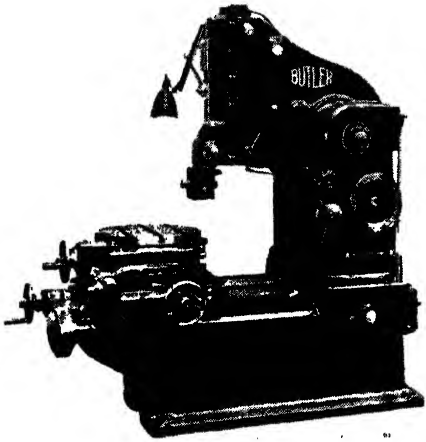


FIG. 454.—8-Stroke Precision Toolroom Slotter.
(By courtesy of Messrs Butler Machine Tool Co Ltd., Halifax.)

press tools, jigs, fixtures, all metal moulds for plastic materials, and gravity and pressure die castings. It is by Butler Machine Tool Co. Ltd. of Halifax, and following the general tendency in design the machine has an individual motor drive which is joined by vee belts to the gear box.

For taper work the upper portion of the body can be quickly tilted backwards or forwards to a maximum of 10°. For the final adjustment a worm and wormwheel are engaged by an eccentric device which permits very fine setting of the machine. On returning the body to its vertical position a fixed spirit level enables the operator to bring the ram vertical to within .0005 in.

As may be judged from the illustration the motions of the table give a longitudinal, transverse, and circular movement, the feed being either manually or power driven. The table itself is fitted with an index plunger for 30°, 60°, 90°, 120°, and 180° movement, whilst the rim of the table is accurately marked in degrees.

With the slotter there are a number of tools and accessories which often prove to be of great usefulness, such as a vertical vice, tools for die work, a rotating tool-holder, a relieving tool-holder or an extension tool-holder, but space prohibits the showing of these items.

CHAPTER XXI

PLANING, SHAPING, AND DRILLING

Planing

THE planer is constructed to produce flat surfaces of larger area than that obtained by means of the shaping machine.

In most cases the work is secured to a moving table, the tool being held in a tool holder, and fed at right angles to the moving direction of the table.

With edge planers used for truing the edges of large plates the work is fixed, and the tool carriage travels in order to take the cut.

A very old type of planer is shown in Fig. 455. It consists of a table with two vee slides fitting in two grooves in the top of the bed, and having two standards supporting a cross bar. The faces of the vertical standards and the cross rail are planed and scraped true. The height of the cross bar can be adjusted by means of a handle working rods and bevel wheels. To the cross bar is fitted a saddle carrying a slide and tool holder, and the saddle can be moved in either direction by hand or automatically through the medium of a square-threaded screw. The tool can be fed up or down by hand, or automatically, and the feed can be altered while the machine is running by reducing the travel of the friction gear.

The table is moved by means of a rack and pinion driven by two pulleys of different diameters, one of which gives a

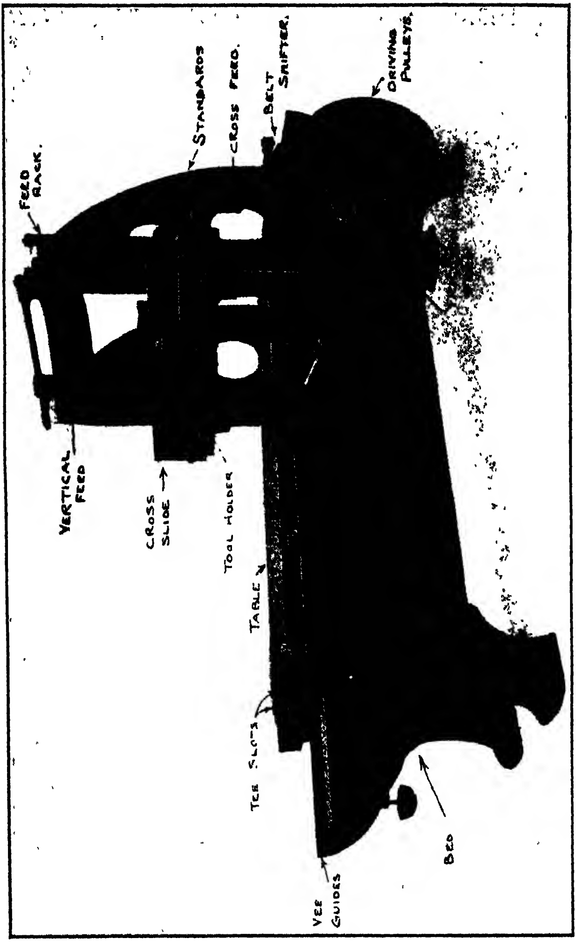


FIG. 455.—Planing Machine.

quick return stroke. The length of stroke is regulated by means of adjustable tappets bolted to the tee-shaped slots in

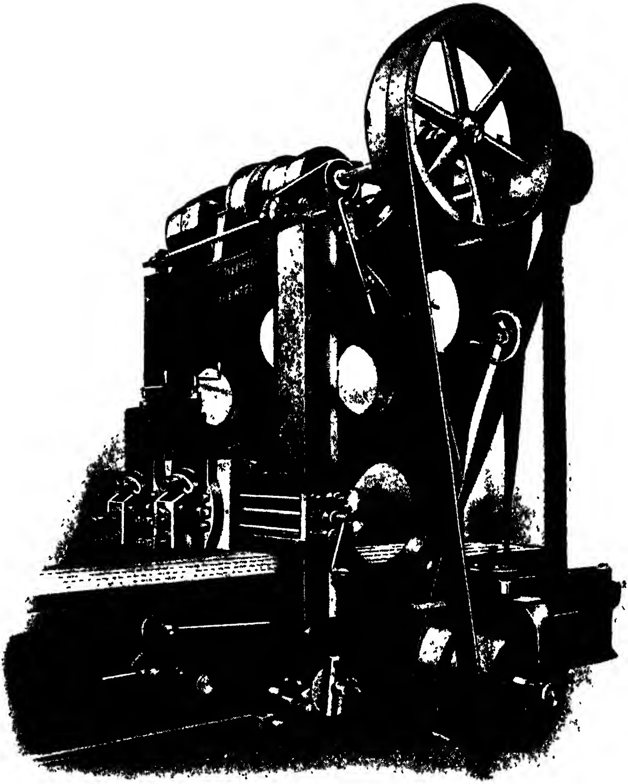


FIG. 456.—" Butler " No. 3 Spur-Gear-Drive Planer.

the side of the table, and which strike a lever operating the belt shifting apparatus.

Modern Planing Machines.—Fig. 456 illustrates a modern type of high-speed planing machine fitted with a belt drive. This is capable of giving best results with high-speed tools and has many important

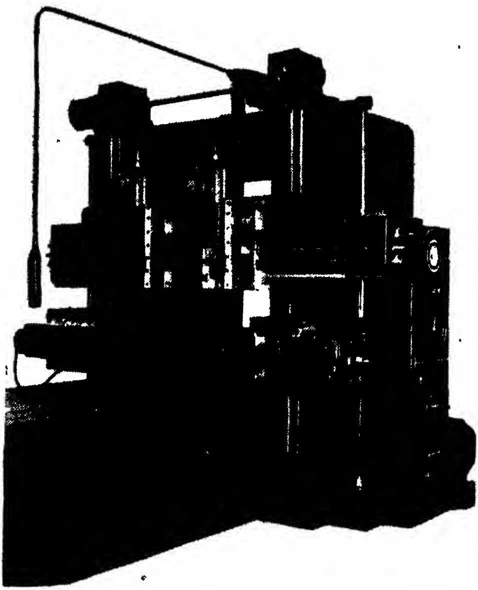


FIG. 457.—Electric Planing Machine.
(By courtesy of Messrs Butler Machine Tool Co. Ltd., Halifax.)

and valuable features. The bed is of great depth, well braced with cross girths of box section. The vees are fitted with an automatic oiling arrangement which will keep them well lubricated. The table is very deep and

well ribbed underneath, the tee slots being cut from the solid. The housings are of box section, securely bolted to the bed, and tied together by a deep cross girth. The heads are graduated for swivelling, and have automatie feeds in all directions. For direct driving a motor of constant speed can be used; this is carried on the top of the machine and always runs in one direction. A planer, also by Butler Machine Tool Co. Ltd. of Halifax, having an individual motor drive, is shown in Fig. 457. It should be appreciated that the designs shown are typical and numerous modifications are made to suit specific manufacturing conditions.

Holding Work.—The method adopted for holding work on the planer depends upon the size and form of the job to be planed.

Small work is frequently held in one or more vices as convenient. If the work is large and heavy, it can be secured by means of bolts and plates directly to the table, tee-shaped slots and holes being provided for this purpose.

For holding and fixing various classes of work, angle plates, parallel packing, levelling wedges, hardwood blocks, stopping plates, and other special devices are required to obtain a correct setting of the work.

It is most important that all work should be clamped down in such a manner as to prevent any slipping or springing of the job, the position of the plates or clamps being determined so as not to interfere with the free cutting action of the tool.

Setting Out Work.—The lining up or setting out of work on the planer is generally accomplished by means of the scribing block, spirit level, and try square. The centres can be obtained quite easily from the bed of the machine.

Cutting Speeds and Feeds. — The question of cutting speeds and feeds is practically the same as with the lathe.

The majority of belt-driven planers have only one cutting speed and that shown in Fig. 456 has one of 40 f.p.m. with 100 f.p.m. on reverse. With the electric driven planers a number of speeds are available and for Fig. 457 they range from 20 to 60 with the reverse varying between 60 and 120 f.p.m.

The feed being adjustable, it can be altered to suit the character of the metal to be cut, and will depend on whether a roughing or finishing cut is being taken. For roughing it is the normal practice to take as deep a cut and as thick a chip as is possible. When finishing, a shallow depth of cut and a coarse feed is chosen providing the operating conditions permit.

Planer Tools.—The shape and form of planer tools are practically the same as lathe tools, but owing to the absence of any convenient method of altering the cutting angle it is necessary to have them ground to the correct angle before using. The clearance should be as small as possible, and for roughing work it is not usual to have a cranked tool, but one in which the end is simply set forward and ground to shape.

In many up-to-date shops tool holders made from mild steel are used, the cut being taken by means of small high-grade steel tools, correctly shaped and held at the end of the tool holder. This effects a great saving in tool steel.

Shaping

The shaper is designed to produce work similar to the planer, but on a smaller scale. It differs from most planers

inasmuch that the tool moves to give the cut. In some shaping operations the work is made to revolve, and in others the tool is fixed in a ram to give the cut, and the work moves to give the feed.

A modern type of shaper is illustrated in Fig. 458. This

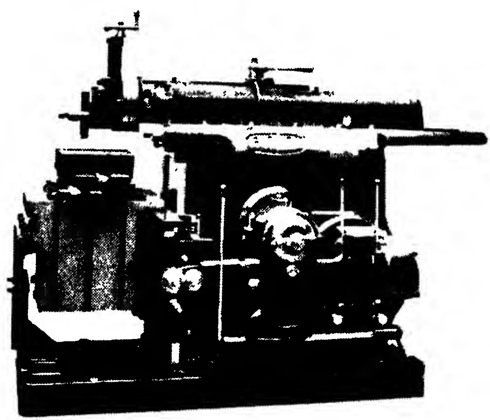


FIG. 458.—Shaping Machine.
(By courtesy of Messrs Butler Machine Tool Co. Ltd., Halifax.)

machine has many interesting features. The main driving link or rocker arm is connected to a ram by a short link which gives a draw stroke, and ensures a smooth cutting action. The stroke can be altered to any position by a crank handle when the machine is running or stationary. The handle controls a pointer which registers the exact length of stroke. The table is vertically adjusted by hand

on the main frame. The cross feed is so arranged that the whole of the feed mechanism can, by depressing a hand lever, be thrown out of action when the machine is running at any speed. The feed can then be altered or reversed with safety without disturbing the driving mechanism. The cross slide is fitted with a micrometer index which can be used for fine adjustments.

Fixing Work.—A great number of shaper jobs can be secured in the vice, which may be swivelled to any position desired. The vice is bolted to the table and fed sideways in either direction, automatically or by hand. When feeding automatically the feeding arrangement works during the return stroke of the ram, the table moving a distance equal to the width of the cut.

Large work can be secured to the top or side of the table by means of bolts and plates, holes and slots being provided for that purpose.

Tools.—The tools used in the shaper are practically the same as in the planer, and often consist of some form of steel tool holder into which tools of various shapes can be clamped.

Circular Work.—Most shaping machines are provided with an attachment for shaping circular work. This arrangement is shown in Fig. 459, and is useful for a large variety of work, such as shaping shafts with solid keys where turning is impossible, or for cutting squares, hexagons, octagons, or circular work. The small sizes are placed direct on the table, and the larger on front of the table slide after the table has been removed, both being arranged to be coupled to the existing feed mechanism to give self-acting horizontal and vertical feed to the work. It is also

possible to fit a dividing plate to this gear, and thus do an endless variety of work without the special marking out of the work.

Cutting Keyways.—An extremely simple and effective apparatus, which will be appreciated by all practical

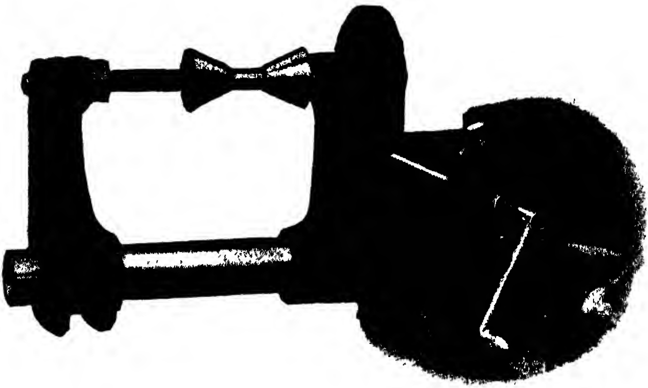


FIG. 459.—Shaping Attachment for Circular Work.

workmen, is shown in Fig. 460. The usual tool box is removed from the ram head, and replaced by a T-slotted plate to which the work can be bolted. The tool is carried on a special bracket mounted on the table of the machine, this arrangement having the double advantage of being far more rigid than the ordinary type of slender overhanging tool, and also keeping the work in full view of the operator. The ordinary feed is available for this operation.

For special classes of work a circular face plate instead of the slotted plate can be used, or a back plate for carrying a chuck.

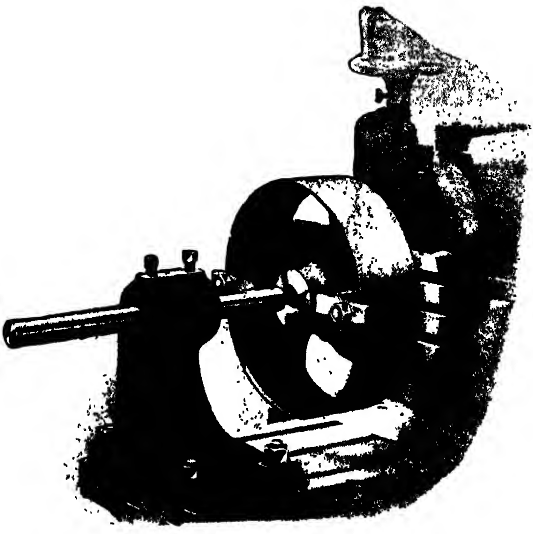


FIG. 460.—Shaping Attachment for Cutting Keyways.

Drilling

Drilling Machines are constructed in an enormous variety of forms. They may be divided into vertical and horizontal drills, radial and fixed spindle drills, multiple and sensitive drills.

The chief features of a good drilling machine are: strength and rigidity of the machine, a good fitting spindle, and, if

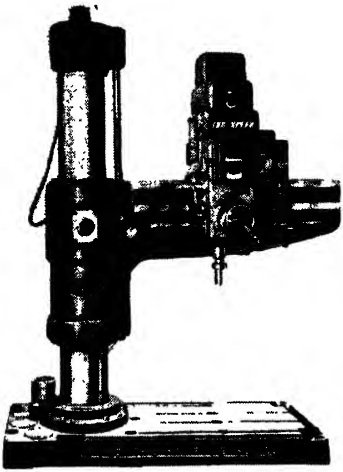


FIG. 461.—Radial Drilling Machine.
(*By courtesy of Messrs W. Asquith Ltd., Halifax.*)

FIG. 462. — High-Speed Motor - Driven Drilling Machine, Pillar Type.

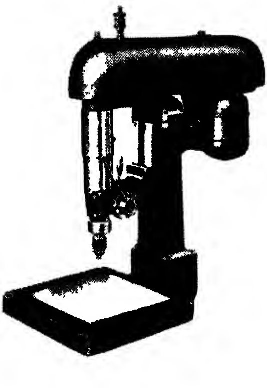


FIG. 463.—High-Speed Motor-Driven Drilling Machine, Bench Type.

of the radial type, a strong swivelling arm free from spring.

In the **Vertical Type** of drilling machine a movable table is provided in order to bring the work correctly under the drill point. The base of the machine is often planed and slotted in order that large or heavy work may be bolted to it.

The **Horizontal Drill** is needed chiefly for drilling work of such a length that it cannot be done advantageously in the vertical drill. These machines have a movable drilling head, and are generally constructed to do such operations as drilling, boring, tapping, and reaming.

A Radial Drilling Machine is shown in Fig. 461, and the various movements are clearly shown. The arm can be swivelled to drill on any portion of the table, and the head can be set over to whatever angle is desired. The spindle can be reversed, started, and stopped by means of one lever, this being of particular use for tapping purposes, both for right and left hand threads.

Multiple or Gang Drills have two or more drilling spindles in the same alignment, or in certain fixed positions. They are generally driven from one common shaft, the spindles being arranged to be run at various speeds and feeds as desired. Fig. 464 illustrates a modern type of multiple drill.

The **Sensitive Drills** are made with one or more spindles which are very sensitive, and should run perfectly true. The feed is given to the drill by means of a lever, and the spindles are generally counterbalanced by means of a weight inside the vertical column.

Drills.—We find several forms of drills in use at the present time, and many great improvements have been made within the last few years. The common or flat

drill may be said to have lost its former position as the main type now available and its place has been taken by the twist drill.

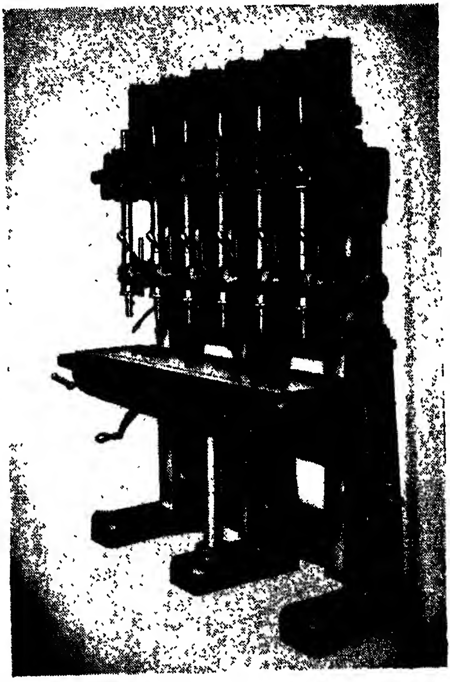


FIG. 464.—Multiple-Head Drilling Machine.
(By courtesy of Messrs Jones & Shipman, Leicester.)

The ordinary high-speed steel twist drill is shown in Fig. 465. These are made with parallel or taper shanks in

sizes from $\frac{1}{32}$ in. to 4 in. in diameter. They are invariably made in the milling machine. The fluting is done by means

FIG. 465.—The Standard Taper Shank Twist Drill.

FIG. 466.—Four-fluted Chucking Drill.

of a special cutter, and the clearance or backing off of the surface is done with an end mill. The flutes are made less in depth as they near the shank, and thus give greater

strength. To obtain this difference in depth the dividing head is raised or lowered sufficiently to give the necessary variation, which is dependent upon the size of the drill. Fig. 466 shows a four-fluted chucking drill.

Drilling.—The location of holes for drilling is frequently done by means of jigs. These are hardened plates, clamped to the work, and through which the drill can pass.

In **preparing work** for drilling it is usual to first chalk the surface and then locate the centre by means of the scribing block, dividers, or some other tool. The centre is then punched, and from that mark a circle is scribed by means of the dividers the same size as the hole to be drilled, and if over $\frac{5}{8}$ of an inch in diameter a smaller circle is also scribed. These circles are lightly dotted with the centre punch, and the work is then set up in the machine. Should the drill run out slightly, the smaller circle will show how much, and it may be necessary to draw it over by means of a groove cut with a bent round-nosed chisel on the side required.

When **drilling large holes** it is the best practice to first drill a small guiding hole. This provides an accurate centre for the larger drill to follow, and will often prevent an untrue hole being made. When drilling cast iron or metal likely to be spongy care must be taken to see that the small drill has gone in quite square.

Cored holes are most unsuitable for drilling, which, besides producing an unsatisfactory job, invariably spoil the drills.

When a cored hole must be drilled, a plate should be clamped above the hole to act as a guide for the drill, and the speed and feed greatly reduced. A new drill should on no account be used for this purpose.

Large holes are frequently cut in sheet metal by means of a cutter and bar, as shown in Fig. 467. A hole is first drilled the same size as the end of the bar, and the cutter is adjusted to diameter by means of a cotter.

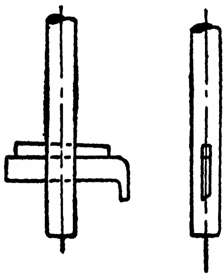


FIG. 467.
Drilling Cutter.

Arboring holes is done by means of a similar type of bar fitted with a flat cutter, which can be adjusted to take various size cuts, and also to arbor the top or underneath side of a hole.

Grinding Drills.—The grinding of the cutting edges of twist drills is of great importance. The cutting edge should have the correct angle and be uniform with the longitudinal axis of the drill, both being exactly equal, and the lips should be backed off or cleared. If the clearance is insufficient or imperfect it will not cut correctly, and when force is applied it resists the power of the machine and is crushed or split. As the drill is shortened through wear and use, the centre gets thicker and will work hard in drilling. To overcome this the centre should be thinned, and care must be taken to remove an equal amount from each side and so keep the point central.

The helix angle of the flutes of a drill are machined to suit each class of material, as is the point angle, and at each resharpening the initial angle should be duplicated.

In most modern workshops twist drills are ground by means of special drill grinders similar to that illustrated in

Fig. 468. The details of this tool can be clearly seen, and it provides an efficient method of accurately and quickly grinding drills.

Speeds and Feeds.—No hard and fast rules can be laid down for speeds and feeds, so much depending

FIG. 468.—Twist-Drill Grinder.
(*By courtesy of William Asquith Ltd.*)

upon the nature of the metal, and as this varies to such a great extent it is impossible to give anything except approximate figures.

The following may be taken as general shop practice with ordinary carbon steel, but with high-speed steel, speeds greatly in excess of these can be used.

SPEED OF DRILLS

The following table shows the revolutions per minute

for drills from $\frac{1}{16}$ to 2 in. diameter, as usually applied :—

Diam. of Drills.	Speed for Steel.	Speed for Iron.	Speed for Brass.	Diam. of Drills.	Speed for Steel.	Speed for Iron.	Speed for Brass.
In.	Revs.	Revs.	Revs.	In.	Revs.	Revs.	Revs.
$\frac{1}{16}$	940	1,280	1,560	$1\frac{1}{16}$	54	75	95
$\frac{1}{8}$	460	660	785	$1\frac{1}{8}$	52	70	90
$\frac{3}{16}$	310	420	540	$1\frac{3}{16}$	49	66	85
$\frac{1}{4}$	230	320	400	$1\frac{1}{4}$	46	62	80
$\frac{5}{16}$	190	260	320	$1\frac{5}{16}$	44	60	75
$\frac{3}{8}$	150	220	260	$1\frac{3}{8}$	42	58	72
$\frac{7}{16}$	130	185	230	$1\frac{7}{16}$	40	56	69
$\frac{1}{2}$	115	160	200	$1\frac{1}{2}$	39	54	66
$\frac{9}{16}$	100	140	180	$1\frac{9}{16}$	37	51	63
$\frac{5}{8}$	95	130	160	$1\frac{5}{8}$	36	49	60
$\frac{11}{16}$	85	115	145	$1\frac{11}{16}$	34	47	58
$\frac{3}{4}$	75	105	130	$1\frac{3}{4}$	33	45	56
$\frac{13}{16}$	70	100	120	$1\frac{13}{16}$	32	43	54
$\frac{7}{8}$	65	90	115	$1\frac{7}{8}$	31	41	52
$\frac{15}{16}$	62	85	110	$1\frac{15}{16}$	30	40	51
1	58	80	100	2	29	39	49

One inch to be drilled in soft cast iron will usually require—for $\frac{1}{4}$-in. drill, 125 revolutions ; for $\frac{1}{2}$-in. drill, 120 revolutions ; for $\frac{3}{4}$-in. drill, 100 revolutions ; for 1-in. drill, 95 revolutions.

High-Speed Drilling

The speeds shown below are taken from a series of tests made at the works of Messrs Alfred Herbert, Coventry, using high-speed twist drills on patent ball-bearing drilling machines. The cast iron was the same mixture as used for lathe beds, the hardness being No. 238 Brinell. It will be seen that the $\frac{7}{8}$-in. hole was drilled at a feed rate of 15 in. per minute, and the $\frac{1}{4}$-in. hole at 50 in. per minute. These speeds are remarkable, but would hardly ever be attempted on general work under ordinary conditions.

CAST IRON.			MILD STEEL.		
Diameter of Drill.	Speed of Drill.	Time to Drill 1 in. deep.	Diameter of Drill.	Speed of Drill.	Time to Drill 1 in. deep.
$\frac{1}{4}$	2,050	$1\frac{1}{5}$ seconds	$\frac{1}{4}$	2,050	$2\frac{1}{5}$ seconds
$\frac{5}{16}$	1,370	$1\frac{1}{2}$,,	$\frac{5}{16}$	2,050	$2\frac{3}{5}$,,
$\frac{3}{8}$	900	2 ,,	$\frac{3}{8}$	900	$3\frac{2}{5}$,,
$\frac{7}{16}$	900	2 ,,	$\frac{7}{16}$	900	$3\frac{3}{5}$,,
$\frac{1}{2}$	900	2 ,,	$\frac{1}{2}$	900	4 ,,
$\frac{9}{16}$	600	$2\frac{1}{2}$,,	$\frac{9}{16}$	900	5 ,,
$\frac{5}{8}$	600	$2\frac{1}{2}$,,	$\frac{5}{8}$	900	$5\frac{3}{5}$,,
$\frac{11}{16}$	600	$2\frac{1}{2}$,,	$\frac{11}{16}$	900	$5\frac{4}{5}$,,
$\frac{3}{4}$	600	3 ,,	$\frac{3}{4}$	900	6 ,,
$\frac{13}{16}$	600	3 ,,	$\frac{13}{16}$	900	7 ,,
$\frac{7}{8}$	600	4 ,,	$\frac{7}{8}$	900	$7\frac{1}{5}$,,

When drilling steel and non-ferrous metals a good flow of a suitable cutting lubricant will permit the drill to run at a higher speed for the same period between each regrind. This is due to the cooling action upon the cutting edges and the washing away of the chips.

Hand Drilling.—Hand drilling is frequently necessary, chiefly in repair work. For this purpose various appliances for holding the ratchet and drill are provided. The most common form is the drill post shown in Fig. 469. This consists of a base plate to which is welded a vertical spindle, which carries a movable arm. The base is drilled or slotted in several places to take bolts for fixing, or it can be held by means of a boiler screw or cramp. The arm can then be swivelled into any position desired, and adjusted to the height required.

The ratchet is generally fitted with a square tapered hole to take a square shank drill.

Portable Hand Drilling Machines are made and designed to work by means of pneumatic and electrical power, and will do work enormously quicker than is possible with the ratchet brace. Holes up to ½ in. in diameter can be drilled by means of these drills by simply using a breastplate, but over that diameter a fixture must be set

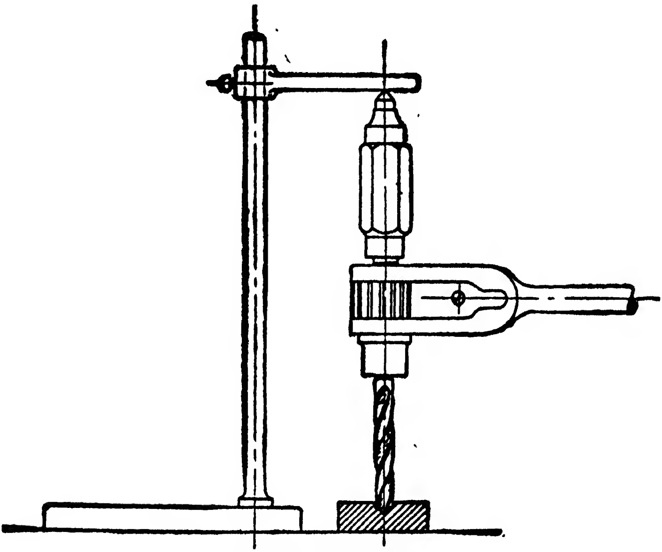


FIG. 469.—Hand Drilling.

up to work in conjunction with a feed wheel and spindle. In both these types of drills, electric and pneumatic, it is necessary to have main power supply, which must be conveyed to the machine through a cable or by means of armoured hose.

It is also possible to adjust these machines to do work such as reaming and tapping.

The magnetic drill post is a most useful tool for repair work. By simply placing the drill post against the plate or job to be drilled, and then switching on the current, the post can be held in any position required.

Decimal Equivalents of the Numbers of Twist Drill and Steel Wire Gauge

No.	Size of Number in Decimals.	No.	Size of Number in Decimals.	No.	Size of Number in Decimals.	No.	Size of Number in Decimals.
1	·2280	21	·1590	41	·0960	61	·03900
2	·2210	22	·1570	42	·0935	62	·03800
3	·2130	23	·1540	43	·0890	63	·03700
4	·2090	24	·1520	44	·0860	64	·03600
5	·2055	25	·1495	45	·0820	65	·03500
6	·2040	26	·1470	46	·0810	66	·03300
7	·2010	27	·1440	47	·0785	67	·03200
8	·1990	28	·1405	48	·0760	68	·03100
9	·1960	29	·1360	49	·0730	69	·02925
10	·1935	30	·1285	50	·0700	70	·02800
11	·1910	31	·1200	51	·0670	71	·02600
12	·1890	32	·1160	52	·0635	72	·02500
13	·1850	33	·1130	53	·0595	73	·02400
14	·1820	34	·1110	54	·0550	74	·02250
15	·1800	35	·1100	55	·0520	75	·02100
16	·1770	36	·1065	56	·0465	76	·02000
17	·1730	37	·1040	57	·0430	77	·01800
18	·1695	38	·1015	58	·0420	78	·01600
19	·1660	39	·0995	59	·0410	79	·01450
20	·1610	40	·0980	60	·0400	80	·01350

CHAPTER XXII

PLAIN AND UNIVERSAL GRINDING

THE chief advantages of grinding lie in the fact that it is the most rapid method of obtaining the degree of accuracy which is required in such a large proportion of modern engineering work. The process of grinding was for many years regarded as a means of sharpening tools, and the emery wheel was considered a superior kind of grindstone.

A lathe adapted specially for grinding cylindrical work, which had previously been hardened, was the initial step towards a more general use of grinding as we have it to-day.

Over a period of years a large number of grinding machines have been designed and put into operation to meet known manufacturing conditions, some of which are illustrated below. Moreover, improvements are constantly being made to the existing types of machines and wheels so that accuracy and surface finish formerly regarded with astonishment is now readily obtained on large-scale production.

It is now possible for certain classes of work to be finished from the solid bar more cheaply, and to a greater degree of accuracy, than by any process of turning or filing. But generally it is more economical to first rough turn the work, leaving the finishing to be done in the grinder.

The advantages of grinding also occur where keyways have to be cut in shafts. This, in the ordinary way, would

be done by machine after the shaft was turned, and consequently it might bend the shaft, so slightly perhaps that it would pass unnoticed. By the grinding method the shaft could be rough turned, the keyway cut, and then ground accurately to size.

It is a very common impression among non-users that because their work is not of a repetitionary nature and they have only one of any particular job that they have no use for the grinder. This is entirely erroneous, as whilst the grinding machine does show to advantage on repetition work owing to its arrangement for accurate feed and automatic trip when the article being ground has been reduced to its predetermined size, these same features also make the machine advantageous on single articles, as after taking a few trial cuts the work is measured for the amount oversize, and the micrometer feed set to take off the remainder, which can be done with great exactness; and it is fairly safe to say that in the majority of cases a greater proportionate saving in the total cost of the job can be made by finishing by grinding single or small numbers of pieces than in repetition work, simply because in the operations previous to the grinding it is not always possible to employ methods such as would be employed when the work has to be dealt with in large quantities. Therefore any saving in cost due to the adoption of grinding for the finishing operation shows to greater advantage in the total cost.

The Modern Aspect of Grinding

At the time this book was first published grinding was not extensively employed in the machine shop for general production. It was principally confined to the tool-room and to special requirements. However, to-day, 1952, it is generally recognised that when parts are required in

appreciable quantity, one of the most economical methods of working to the fine limits of modern production is to turn, mill bore, or plane, as the case may be, and then to finish the component by grinding. Moreover, between the machining and grinding, the necessary heat treatment of the steel can be effected and the hardened surfaces thus produced can be economically ground to size.

The amount of stock which can be economically removed by grinding depends, in the main, upon the size and power of the grinding machine. For ordinary commercial grinding the work is as a rule reduced to somewhere between $\frac{1}{64}$ in. and $\frac{1}{32}$ in. of the required size. When the material has been machined to this dimension and then hardened, grinding is the only way of bringing the article to size.

A production cylindrical grinder is specially constructed for the work in hand. Hence it differs from a machine intended to handle a large range of work in the tool-room or general machine shop. The design of a universal grinder, of which an example is given in Fig. 470, may be similar in its basic principles to a plain grinder, but it differs in its special features and the auxiliary attachments which make it adaptable for a wide range of work. For instance, the wheel slide on the universal machine can be swivelled with relation to the table; the headstock can also be set at an angle, and provision is made for revolving the headstock spindle for grinding parts held in a chuck or otherwise. With a plain machine the wheel slide is set permanently at right angles to the table travel and the headstock does not swivel.

Whilst the mechanical details naturally vary with different makes, the majority of cylindrical grinders are similar to that shown in Fig. 471.

The usual method of grinding externally a cylindrical part is to rotate it on two "dead centres," both of which remain stationary. The object of grinding work while it revolves on stationary centres is to secure accuracy, for then any slight error which may be in the spindle bearings is not reproduced in the work. If the workstock centre rotates with the component, as in the case of a lathe, any eccentricity of the centre would result in inaccurate grinding. Therefore, when externally grinding cylindrical parts on centres both are made "dead," *i.e.*, do not rotate. Yet it should be realised that for some classes of grinding, as, for example, when grinding parts held in a chuck attached to the spindle, it is necessary to rotate the workhead spindle.

Churchill Universal Grinder

A Churchill universal grinder is shown in Fig. 470. The external grinding wheel spindle has "Hydrauto" automatic bearing adjustment. In this patented construction of bearing the correct running adjustment is automatically maintained in such a way that whilst only slight pressure is applied for correct running adjustment a definite lock is obtained and prevents any movement of the spindle from its true running axis. The "Hydrauto" principle, coupled with a Nitralloy spindle, gives a bearing of the highest precision, cool running and one which ensures maximum efficiency from the grinding wheel whatever the nature of the work.

Both the wheel and work heads may be swivelled into any desired angular position whilst accurate scales indicate the setting. The wheelhead is fitted with a double slide so that the feed may be in any direction irrespective of the angle at which the head is set.

The method of changing over from external to internal grinding and vice versa is simple, as the external grinding wheel does not have to be removed or swivelled out of the way. Hence the complete change over is made simply by swinging the internal spindle into or out of position as required. Barrel type internal grinding spindles with adaptor extensions are used on the machine.

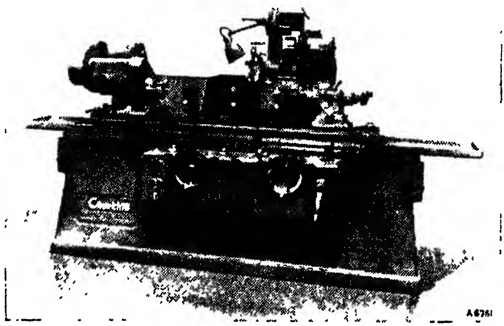


FIG. 470.—Grinding Machine.
(*By courtesy of Messrs Churchill & Co. Ltd., Broadheath, Nr. Manchester.*)

Precision balanced constant speed totally enclosed motors for external grinding wheel spindle drive, internal spindle drive, and table drive ensure exceptionally smooth and trouble free running under all conditions.

Standard equipment includes an internal grinding spindle with adaptor extensions covering a generally useful range of work.

The workhead spindle is of a large diameter running in a bronze pad-lubricated cone bearing immediately behind the faceplate and a ball journal bearing at the opposite

end. The design allows for live or dead centre grinding and for ready conversion from one to the other.

The work drive is by constant speed precision balanced motor. Four work rotation speeds are obtainable by a quick-change device. An automatic brake is incorporated for quickly stopping work rotation. The hydraulic table traverse speed is variable and can be adjusted exactly to the requirements of the work by a sensitive control. Stroke length is adjusted by quick-setting trip dogs with fine adjustment for grinding up to shoulders. The dogs are carried in steel slots on the front edge of the table. Sensitive, light hand motion is also fitted, and is immediately engaged or disengaged by a finger-tip control operating hydraulically.

Automatic cross feed of the grinding wheel operates at each reversal of the table and can be varied from minimum to maximum whilst grinding. The new hydraulic reverse valve mechanism operates satisfactorily down to $\frac{1}{8}$ in. traverse. Quick hand feed is also fitted.

The tailstock spindle is hardened and ground. It is fitted with a dust cap and is spring loaded to allow for axial expansion of the work. Movement of the centre is lever operated on the 10-in. × 24-in. machine. On the larger machine a hand wheel is fitted.

Complete wet grinding equipment is included in the standard equipment. The swarf separator tank is separate from the body. Coolant is delivered to the work and is returned direct with the swarf to this tank, which is of a new type giving highly efficient separation of swarf. Deposited swarf can be readily removed. From this main tank, coolant is passed into the pump chamber in the body. The motor-driven pump is submerged and is always primed.

Finger-Tip Control.—The machine is fitted with

"finger-tip" control to the hydraulic table traverse, which is an entirely new feature and results in increased output and a marked improvement in accuracy. An outstanding advantage of "finger-tip" control is its simplicity and ease of operation, which adds considerably to the efficiency and safety of the machine.

To operate the control it is necessary only to move a

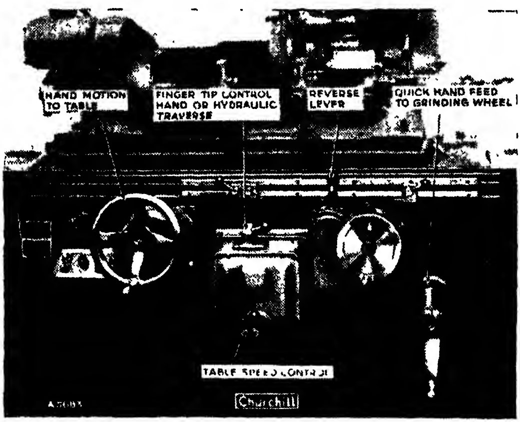


FIG. 471.—Cylindrical Grinder showing Table Control.
(By courtesy of Messrs Churchill & Co. Ltd., Broadheath, Nr. Manchester.)

small lever mounted on top of the valve box which, according to its position, either engages or disengages the table traverse. Movement of the lever towards the operator causes the oil pressure to disengage the hand motion and engage the hydraulic traverse or vice versa. Thus the table traverse oil circuit is brought into use, the direction of traverse then being controlled by the reverse lever in the usual manner. The arrangement of movement of the control away from the operator to engage

the hand motion is a safety precaution; if the operator accidentally leans against the control lever the table stops and no damage can result.

"Finger-tip" control is a refinement which enhances still further the smooth and sensitive operation of a grinding machine. The control provides an excellent method of giving "dwell" at each end of the traverse, entirely under the direct control of the operator.

A swarf separator gives the following advantages: higher finish on the work; more consistent sizing; more metal removal per horse-power used; less wheel wear; less heating of the work and consequently less distortion; longer wheel life between truings with less diamond wear; up to 98 per cent. of metal and abrasive swarf removed before coolant recirculated.

The Churchill swarf separator operates on the following system. The flow of the coolant from the grinding machine is discharged tangentially into the circular tank thereby giving a circular motion to the coolant which deposits the swarf at the perimeter of the tank. Recirculation from the tank is from a central orifice placed just below the top level of the coolant. In practice, about 2 cwts. of swarf can be deposited in the separator before cleaning out is necessary. Cleaning occupies only a few minutes.

Internal Grinding Machine

An internal grinding machine specially designed for the rapid production of small parts, such as ball bearings, is shown in Fig. 472.

Convenience of operation has been specially studied, the movement of a single lever stopping the power traverse of the table and enabling same to be wound away from the wheel quickly for gauging purposes.

A return of the table to the operating position, and the reverse movement of the lever, engages it with the power traverse in exactly the same position as previously.

The work is stopped and started directly on the work head itself, and not through the medium of the countershaft, fast and loose pulleys being fitted directly on the work head spindle, the loose pulley being on ball journal bearings.

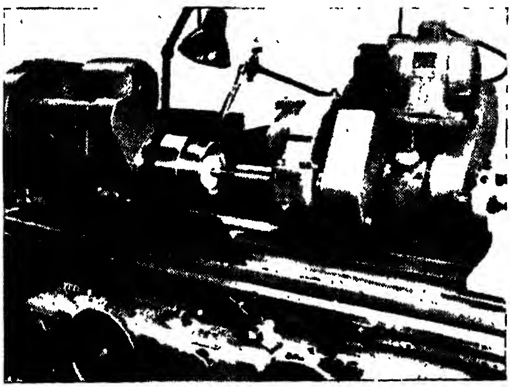


FIG. 472.—Close up of Internal Grinding Machine.
(By courtesy of Messrs Churchill & Co. Ltd., Broadheath, Nr. Manchester.)

The spindle is hardened and ground. The spindle nose is screwed, and has two separate diameters for registering fixtures, as in standard practice, so that fixtures can be frequently changed on the machine without impairing their accuracy.

The internal spindle is carried on a slide of ample proportions which is rigid and thus enables work to very fine limits to be produced continuously.

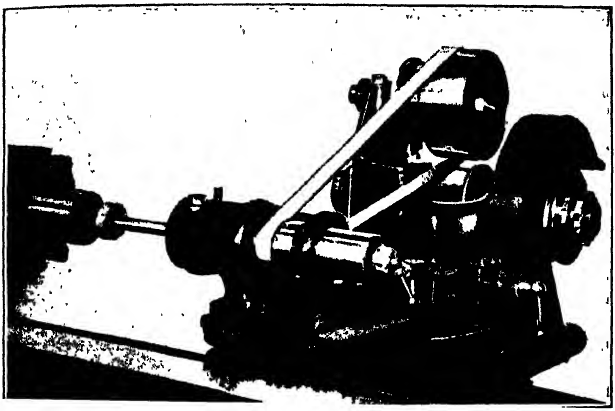


FIG. 473.—Internal Grinding.

FIG. 474.—Grinding Machine.
(*By courtesy of Messrs Churchill & Co. Ltd. Broadheath, Nr. Manchester.*)

Universal Tool and Cutter Grinder.—Fig. 475 illustrates a modern type of universal tool and cutter grinder. This machine will grind accurately and quickly within the limits of 10 in. × 21 in. The wheel headstock swivels, so that either cup or face wheels may be used.

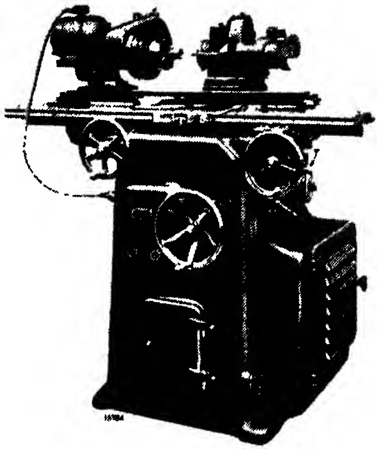


FIG. 475.—Herbert's No. 16 Motor-Driven Universal Tool and Cutter Grinder.
(By courtesy of Messrs A. Herbert & Co., Coventry.)

The spindle is provided with dust-proof ball bearings. An adjustable wheel guard is fitted, enabling the grinding wheel to be changed without removing the guard. The table can be swivelled for grinding taper and conical work. Stops are fitted to a rod on the front of the table for limiting the movement in either direction. The universal headstock swivels horizontally and vertically and is graduated. The spindle is bored to take a standard

taper, and the nose is machined so that a chuck, driver plate, or face plate may be fitted. The driver plate is fitted with a taper bronze bush, so that work may be ground on dead centres, and the spindle may be locked or allowed to revolve as desired.

Two adjustable headstocks are fitted to facilitate the grinding of hobs, taps, reamers, gear cutters, etc., where it is necessary that the work should pass under the wheel.

Surface Grinder

The Surface Grinder.—This type of machine is used for such work as finishing piston rings, discs, thrust collars, saws, milling cutters, and similar work.

FIG. 476.—Surface Grinding using a Non-Electric Magnetic Chuck.
(*By courtesy of Messrs J. Neill & Co. Ltd., Sheffield.*)

The crosshead which carries the wheel slide is usually adjustable, so that surfaces may be finished either perfectly flat, convex, or concave, as may be desired.

FIG. 477.—Universal Tool and Cutter Grinder.

When fitted with a magnetic chuck this type of machine will grind the thinnest possible work.

The travel of table is automatic in either direction, and

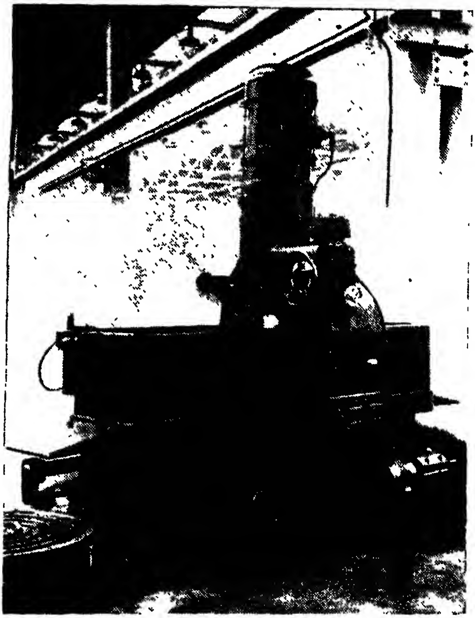


FIG. 478.—Vertical Type Surface Grinder.
(*By courtesy of Messrs Lumsden & Co. Ltd., Gateshead-on-Tyne*)

is controlled by means of dogs operating against a reversing lever. The lever can be turned down and the table moved beyond the reversing points without changing the dogs.

A surface grinding machine is shown in Fig. 478, and can be used for wet or dry grinding.

In Fig. 479 is shown a modern surface grinder by The Churchill Machine Tool Co. It is a class of machine which is extensively employed not only for finishing operations but for machining castings and forgings direct from the black. In this connection a high output is looked for, and an important factor is the correct traverse speed. On the machine shown the table travel covers a wire, whilst speed selection is very convenient.

A table travel up to 60 ft. per minute is possible with the Churchill hydraulic mechanism. Furthermore, at all speeds table movement is smooth and free from shock or jar at the reversals. Stroke length can be set very accurately by means of trip dogs.

Loading of the table and inspection are greatly facilitated, as the table may be run clear of the grinding head merely by depressing a plunger on the reversing lever. When the table is in the withdrawn position, movement of the reversing lever returns it to the grinding position where the working stroke automatically resumes. Location of the trip dogs is undisturbed and there is no danger of overrun on the withdrawal.

Oil is used in the hydraulic system and the necessary pressure for traversing the table is developed by a simple constant delivery gear pump.

The segmental type of grinding wheel chuck enables abrasive segments to be worn to one-sixth of their original size. In addition to possessing freer cutting properties than the continuous surface wheel, the segmental wheel is lower in initial cost. It is also an advantage that fracture at one point does not necessitate the replacement of the entire wheel. The conical plate construction of the segmental chuck precludes all possibility of deflection under the heaviest of cutting. Rigidity in the

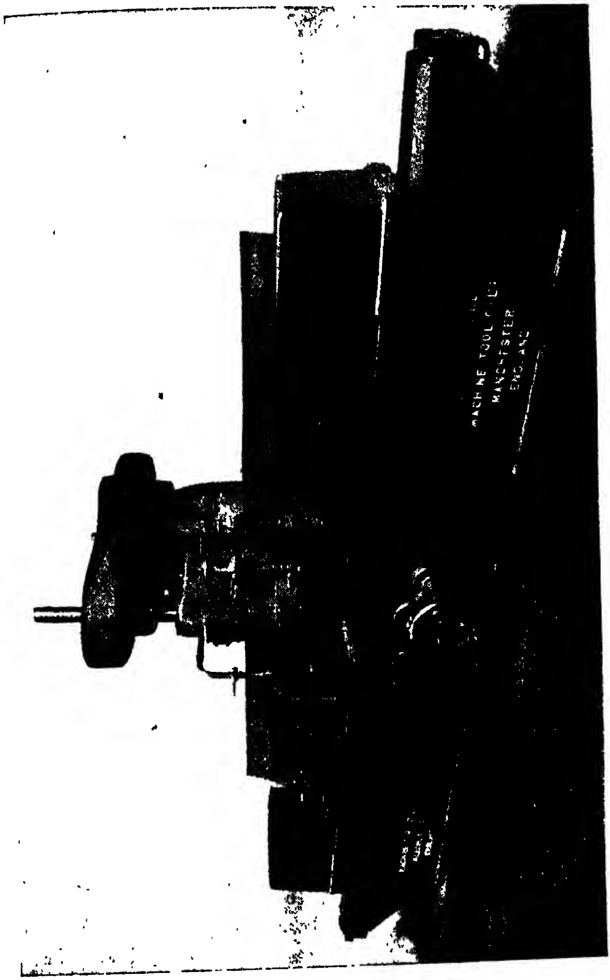


FIG. 479.—Modern Surface Grinder.

wheel chuck is another factor ensuring grinding wheel economy.

On the belt-driven machines the chuck is secured to a flange forged solid with the grinding wheel spindle, whilst the motor-driven wheel-head embodies a flanged sleeve for attachment of the chuck. Another special feature of this machine is the grinding wheel spindle mounting shown in Fig. 480.

The grinding wheel spindle runs in a special assembly of heavy-duty ball bearings, whilst on the heavier machines roller journal bearings are used. Thrust is taken on ball-thrust washers and a spring-loaded device is incorporated to prevent lost motion in the feed readings, due to end play in the bearings. The wheel-head is counterbalanced and subjected to an upward pull to overcome lost motion in the gearing. The grinding wheel spindle is not subject to any lateral stress from the belts and transmits only the grinding torque.

Vertical adjustment of the grinding head is not impaired by the drive, for the wheel spindle is splined to take the drive from the pulley sleeve. From the vertical drive shaft situated at the rear of the column the drive is transmitted to the grinding wheel spindle by multi vee belts. Belt tension is maintained and a large arc of contact ensured by an automatic tensioning device.

Face Grinding

The surface grinder, as shown in Fig. 479, is sometimes referred to as the planer type from its being designed

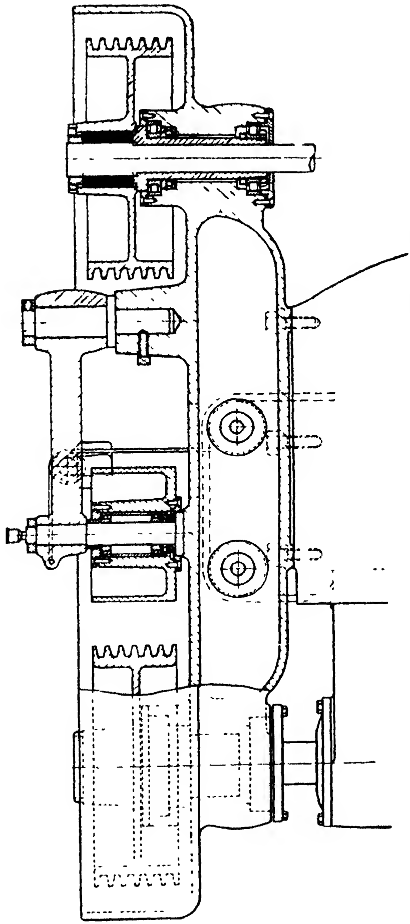


FIG. 480.—Spindle Construction of a Churchill Grinding Machine and Hydraulic Bearings.

on the lines of an ordinary planer, and its purpose has

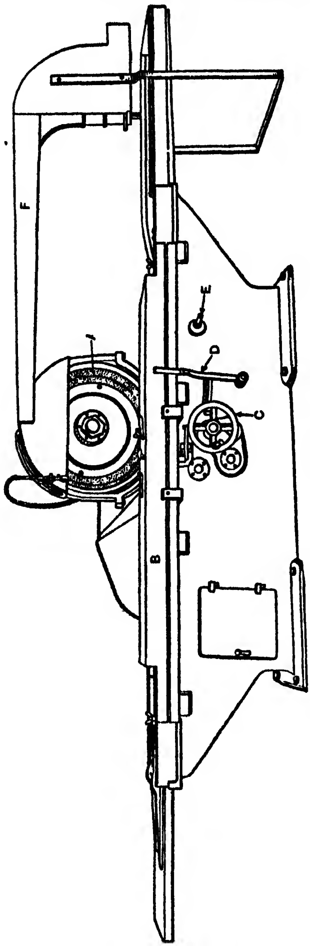


Fig. 481.—Face Grinder.

already been alluded to, but for certain classes of flat grinding the face grinder may be preferable to the one which uses a wheel which grinds on the periphery. Its advantages may be said to be similar to those which attach to the face-milling cutter, which suits certain classes of work better than an axial cutter. The power consumption is less and the plane surfaces are produced with fewer passes of the grinding wheel. The radius of a cup wheel also remains the same until it is worn out, instead of changing constantly, as with a disc wheel. The type of face grinder shown in Fig. 481 is generally used for grinding quite heavy parts, and it is especially adapted to that class of work which can be held to better advantage when the surface to be finished is in a vertical

plane. For example, the ends of rather long castings, such as machine legs, can easily be ground on this style of grinder, because the work can be clamped to the table of the machine in a horizontal position. It would be impossible to grind work of this class on a normal machine having a vertical spindle, because of insufficient space between the machine table and wheel. The horizontal face grinder is used in locomotive shops for truing or finishing the bearing surfaces of guide-bars and can be employed to advantage for many other grinding operations.

In respect of the working of the machine, the work is traversed past the edge of the ring wheel A and the part being ground is attached to table B, which has an automatic reciprocating movement. The exact method of holding the work depends upon its shape. Very often the parts to be ground are supported by angle plates. The table on this particular machine is 2 ft. wide and about 11 ft. long. The length of the stroke is regulated by dogs which engage a reverse lever. The wheel has an adjustable automatic power feed, and both the wheel and work table can be moved by hand. The hand wheel C is used for traversing the work table by hand; lever D is for starting and stopping the table, and a crank on shaft E may be used for the cross feed of the wheel. This machine is so arranged that it may be controlled from either the front or the rear: it is a convenient feature as, ordinarily. when a grinding operation requires a relatively long time the operator stands at the rear of the machine while the grinding is in progress in order to have an unobstructed view of the work.

Automatic Operation.—An important feature of a grinding machine is the automatic feed. On the modern machines, each time the table reverses the wheel may be fed forward anything from 0.00025 to 0.004 in. according

to requirements, and when this is set a large number of parts can be automatically ground to size by an unskilled operator. In order to keep down the wear of the wheel the parts should be turned reasonably close to the grinding limit.

Internal Grinding

The principal feature of the internal grinder, as shown in Fig. 482, is the very high speed necessary for the small wheel, on account of nearly all grinding work

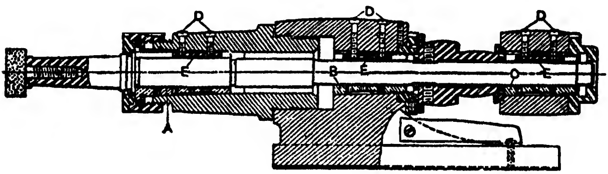


FIG. 482.—Spindle of Internal Grinder.

being done with a high surface speed. Sometimes a grinding wheel spindle may have to operate at 30,000 revolutions per minute, calling for a ball-bearing spindle construction, as shown in Fig. 482.

In Fig. 484 is shown an automatic internal grinder. This is a production machine with a high output. Operating on the plunge cut principle, the machine is intended for short bores; for bores the length of which is not greater than twice the diameter and as a maximum does not exceed 2 in. (50 mm.). A given size of bore can be repeated an indefinite number of times, size within 0.0002 in. being obtained automatically and without gauges being used except in the initial *set-up*. When specially equipped the machine will grind faces or shoulders adjacent to bores.

After the work-piece is inserted and the lever is moved to start the cycle there is no other operation to perform until the finished component is removed. The machine automatically stops with the work-head in the withdrawn

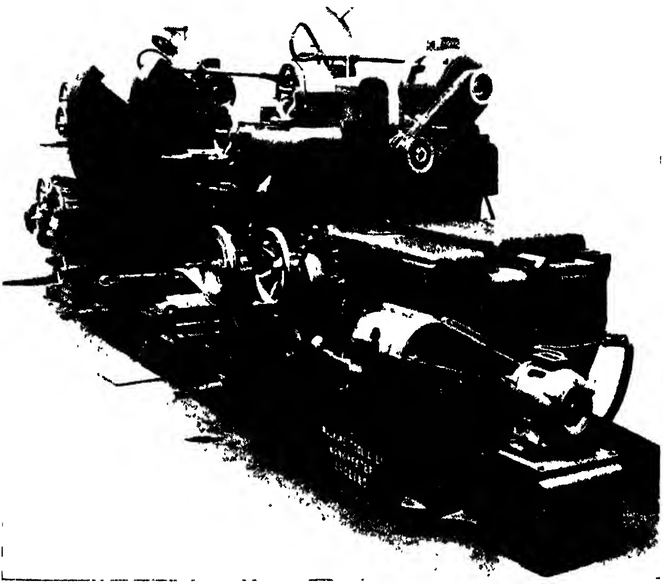


FIG. 483.—Modern Internal Grinder

position ready for the removal of the sized component and the insertion of the next unground one.

The cycle of automatic movements after start up is as follows :—

Rapid advance of work-head towards the grinding wheel ; the grinding wheel-guard lifts.

Truing device falls into operating position and table speed automatically retards to truing speed.

Wheel truing. Truing device lifts clear of work.

Simultaneous commencement of work-head oscillation and grinding wheel feed movements.

Fall away of grinding wheel from bore.

Rapid run-out of work-head. Guard lowers to cover grinding wheel.

Automatic knock-off of all motions excepting grinding wheel spindle.

The movement of the table when grinding is a short high-speed oscillation which can be adjusted for length of movement, the maximum being ½ in. This dimension and the width of the grinding wheel limit the length of bore ground.

For the high-speed oscillation, and also for the high-speed positioning traverse, the work-head is moved, being mounted on a table with long guiding surfaces, whilst the grinding spindle is mounted on a cross slide which spans the table and is stationary excepting for feed movement.

The feed is applied continuously throughout the grinding operation by a cam, but the rate of feed varies, giving a high rate of metal removal at the outset and building up the necessary quality of finish in the latter stages with a diminishing rate of feed. The oscillatory movement continues after feed adjustment has ceased, thus allowing the cut to die out.

Grinding Taper Bores

This machine is not restricted to the grinding of parallel bores. Adjustment for taper grinding is made by swivelling the work-head. There are two separate swivel

adjustments. Coarse settings are made by swivelling the work-head on the sub-base, whilst the latter can be adjusted by means of a fine screw and nut for alignment purposes and accurate settings of small degrees.

Combined Internal and Face Grinding

Substantial economies can often be effected by grinding an adjacent face at the same setting as the bore. The machine in Fig. 484 can be equipped for such operations.

When the face is located at the bottom of a bore the facing operation is performed with the internal grinding spindle, but when an outside face has to be ground an additional spindle, similar to the internal spindle, but carrying a larger wheel, is placed alongside the internal spindle. The facing operation takes place during the automatic feed cycle.

The feed for face grinding is applied by hand, and adjustable dead stops control the amount of metal removed from the face and also the position of the face in relation to the bore. A separate wheel truing device is used for the face of the grinding wheel.

Fig. 484 depicts the main features of a modern internal grinding machine by the Heald Co. Of American origin, though extensively used in this country, it is fully automatic.

This internal grinder not only can be used as a single purpose tool maintaining the highest efficiency on mass production, but one that may be used for a variety of work.

While the capacity, power, rigidity, speeds, and feeds permit its use on work that might be termed " medium sized," yet it was primarily built for small holes. It is useful on work such as ball races and gears with very

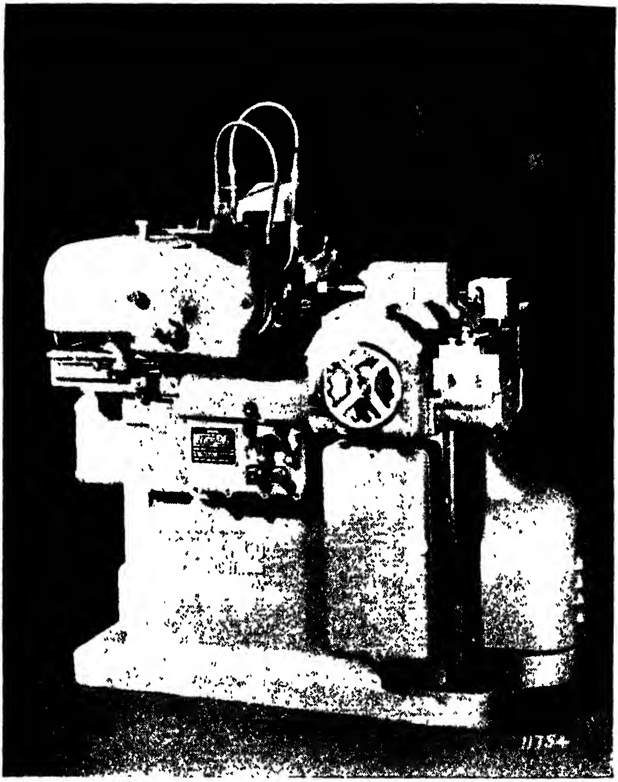


FIG. 484.—Heald Grinder.

small holes. Hence, these parts are manufactured commercially and finish ground to very close tolerances.

In addition to the above features this machine has an

improved hydraulic drive for the table, and the wheel truing device, work-head, and fixture operating mechanism are all hydraulically controlled in accordance with modern practice.

Automatic Operation.—The diagram in Fig. 485 indicates the cycle of operations for fully automatic internal grinding. The cycle starts immediately after the operator has chucked the work and thrown over the starting lever, the work going up to the wheel with fast travel of the table. As the wheel is about to enter the hole it recedes and by a pick-up feed is brought in contact with the work in what might be called a plunge cut. This function eliminates any chance of breaking down the corner of the wheel as it enters and also helps where there is an irregular amount of stock left for grinding. The feed now changes to the proper roughing feed and the reciprocation of the table is the correct roughing speed. This rapidity removes a large amount of the stock. Then at a predetermined point the feed changes to a finishing feed, relieving the strain and spring of the spindle before truing the wheel. When the hole is to nearly finished size the wheel recedes and the work withdraws from the wheel. The table changes to proper truing speed, the diamond drops into position, the wheel is trued, and again recedes as it re-enters the hole. The wheel is now grinding with a finishing feed and the table has changed to the proper finishing speed.

When an extremely fine finish is desired there can be included in the grinding cycle a spark-out feed where the feed is practically nothing. When the exact required size of work has been reached the wheel backs off and the work withdraws, eliminating any chance for bell mouth or scratches in the finish. All units go to the rest position and the grinding cycle is complete. These

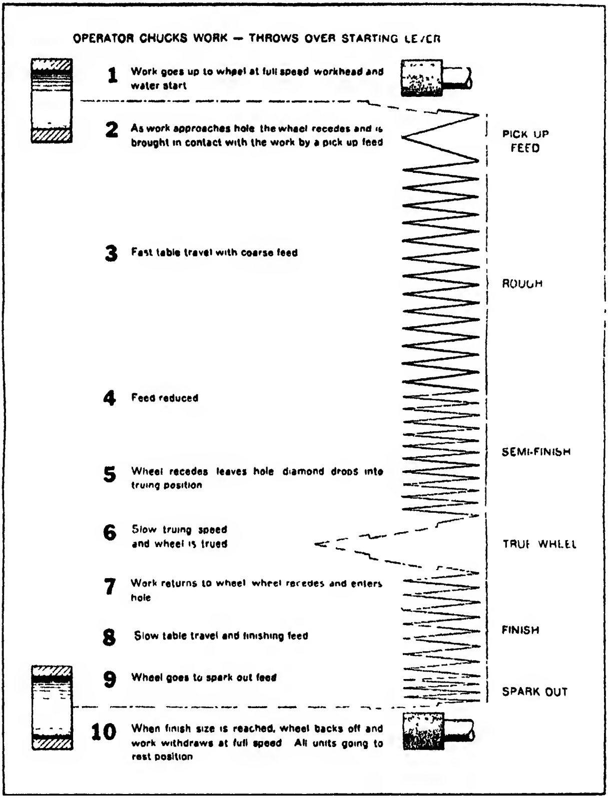


FIG. 485.—Automatic Grinding Operations

automatics make possible new standards in refinement and uniformity which are so much in demand to-day, even on the lowest priced articles.

Plain Grinding Machines

Fig. 486 shows the essential features of a modern plain grinder with Churchill's " Hydrauto " patent bearing.

The finish produced, and the lasting properties of the

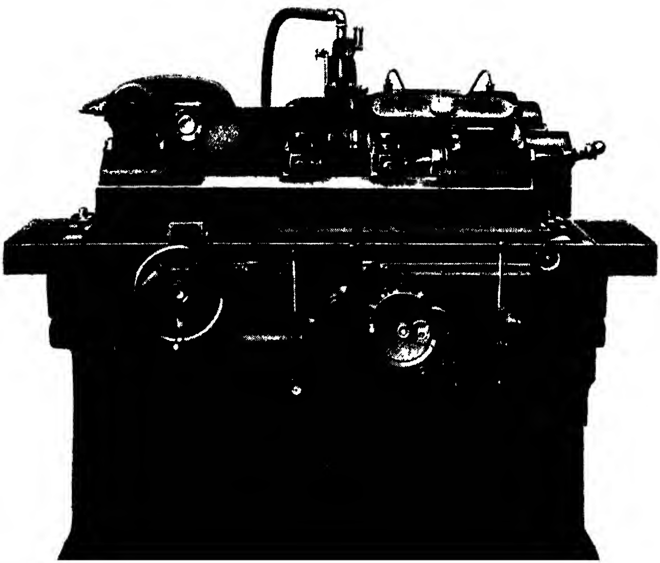


FIG. 486.—Modern Plain Grinder.

grinding wheel, depend upon steady running of the grinding wheel spindle. With the normal design of bearing, the adjustment must be such that the oil will circulate freely when cold. When the correct temperature has been reached after a period of running there is bound

to be a definite looseness of the spindle in the bearings, due to the lowered viscosity of the oil and the expansion of the bearings. In other words, the bearings cannot be adjusted to running temperature conditions, and the clearance that must be allowed has a detrimental effect on finish that is obtained. The lasting properties of the grinding wheel are not at their best.

On the other hand, the patent "Hydrauto" bearing automatically adjusts itself so that the spindle runs under the same conditions when starting from cold as it does when running temperature has been reached. The oil film, at running temperature, is exceedingly fine and cannot be distorted. The spindle rotates on a perfectly true axis, and therefore the grinding wheel must form a perfect cylinder. In this way the whole periphery of the wheel is brought into use, giving higher finish and extending the periods of time that elapse between wheel truing.

The pressure holding the top bearing in contact with the spindle is applied hydraulically. It is a steady but resilient load which is prevented from failing by a device incorporated in the hydraulic system.

Form Surface and Taper Grinding

In mass production work it very often pays to finish the external surfaces of simple parts by a formed wheel in the same way as such parts are made on capstans and automatics by formed tools. The wheels have to be shaped by a special fixture, but a large number of parts can be ground without re-shaping the wheel. Taper grinding is a comparatively important operation, because very frequently shafts have to be taper turned and then ground to fit accurately into the taper bore of, say, a gear wheel, crank, pinion, or propeller. Here,

as shown in Fig. 487, the work is placed between the centres and the table is set to the required angle a, as shown by the graduations at one end. This adjustment locates the axis of the work at an angle with the line of motion of the table; hence a taper is produced, the angle thereof depending upon the amount that the table is turned from its central (parallel) position. While there are graduations on the swivel table reading, in most cases to both

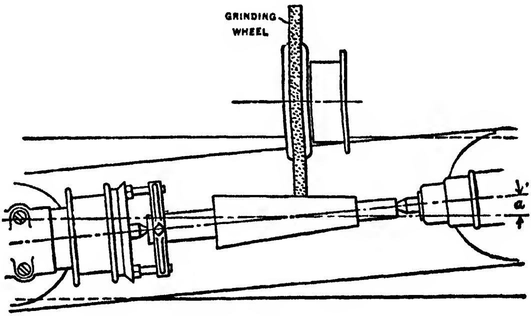


FIG. 487.—Taper Grinding.

degrees and inches per foot, the taper should be tested by a suitable gauge before parts are ground to finished size.

As regards the flat grinding of comparatively thin parts, this can be economically done by means of a cup wheel and an automatic or magnetic chuck. The sides of piston rings constitute a good example of this class of work. These chucks are easily and quickly operated and they make it possible to obtain a greater degree of accuracy, in many cases, than could be obtained by the clamp-and-bolt method of fixing. The method of holding work to the table of a surface grinder depends more or less upon the shape of the part to be ground. Ordinary clamps and bolts are sometimes used, but where available magnetic chucks

(see Figs. 243 and 245, pp. 269 and 282) are preferable for most work.

The Angle Head Machine

This is a further development in the important operation of plain grinding shown in Fig. 488. This type of machine, by performing two operations, grinding of a cylindrical portion and an adjoining face at one setting, has opened up new channels for the application of precision grinding. The accuracy of one ground surface in relation to the other is definitely ensured, idle time is eliminated, and output greatly increased.

Machines can be supplied to operate with the table stationary, that is, when the length of the cylindrical portion does not exceed the width of the grinding wheel face, or the table can be arranged to traverse in the manner of the normal plain grinder. On components where it is necessary to produce a face at right angles to a previously machined bore the angled head machines offer, in many cases, the most efficient method of operation.

The diagram in Fig. 489 shows the method of operation when grinding two surfaces. The grinding wheel-head spindle is permanently set at 45° and the face of the grinding wheel is trued in the form of a right angle vee. For grinding the cylindrical portion the wheel-head is moved forward at right angles to the centre line of the work, after which the table is moved by hand up to the dead stop in order to grind the face.

The work-head spindle runs in widely spaced adjustable bearings which are automatically lubricated, and a smooth final drive is ensured by the use of hardened and ground worm and bronze worm wheel. The worm spindle is driven by the Churchill compensating belt drive, a four-speed box mounted on the front of the bed providing a

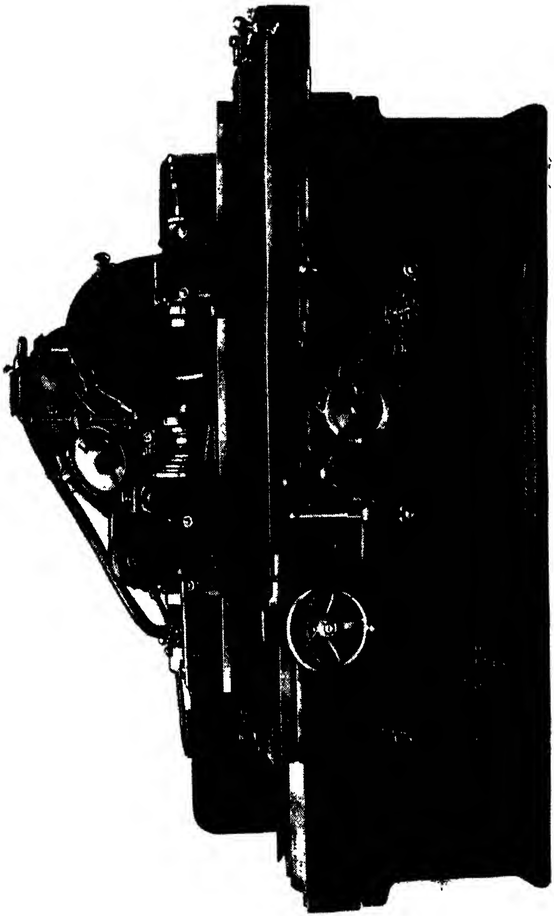


FIG. 488.—Angle Head Grinder.

range of four work speeds. The nose of the spindle can be made to suit the requirements of the work, and can be fitted with fixtures, expanding collets or drawback collets operated by mechanical or by pneumatic means. A special

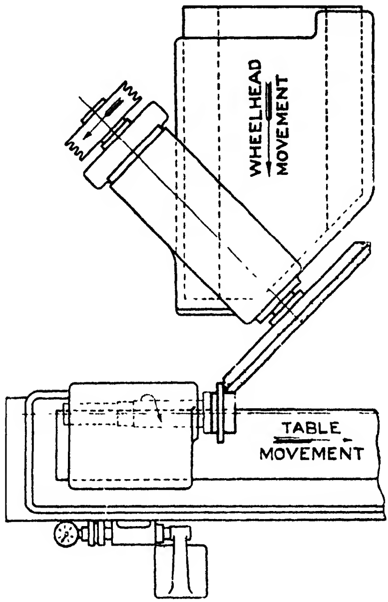


FIG. 489.—Grinding Two Surfaces.

feature of the Churchill lever-operated collet mechanism is that it can be quickly changed over for operation either by thrust or pull.

This form of work-head used when the component has to be carried between centres has a spindle secured in the main casting which is clamped to, but adjustable

along, the deep angular section work table. A drive or carrier plate rotates about the nose of the spindle, the final drive being by worm and worm wheel. The drive and the bearings are automatically lubricated. Transmission of the drive from the four-speed gear box to the work-head is by the Churchill compensating belt drive.

Usually the tailstock is only necessary when the machine is required for dead spindle grinding. The spindle is spring loaded to allow for axial expansion of the work. Withdrawal of the centre is lever-operated, and a plunger holds the centre in the withdrawn position until released by depression of a thumb latch on the lever handle. Placing of heavy work between centres is greatly facilitated by this device as it leaves the operator's hands free when inserting the work. The spindle can be clamped in any position throughout its movement. An efficient seal prevents dust and foreign matter damaging the spindle.

Crankpin Grinding Machine

The machine shown in Fig. 490 was designed for the particular purpose of grinding crankpins of locomotives in position in the wheels. By this method a dead smooth surface can be produced concentric with the original centre, and the amount of metal removed being the minimum necessary to produce a true pin.

In cases where excessive material requires removal from the pins, it may be necessary to turn them prior to grinding, and would have to be done by some form of turning attachment.

The machine is manufactured by Messrs Beyer, Peacock, & Co., and consists of a horizontal grinding head in which a steel spindle revolves at 500 revolutions per minute. This spindle has an eccentric motion imparted to it by sleeves driven by worm gearing. The amount

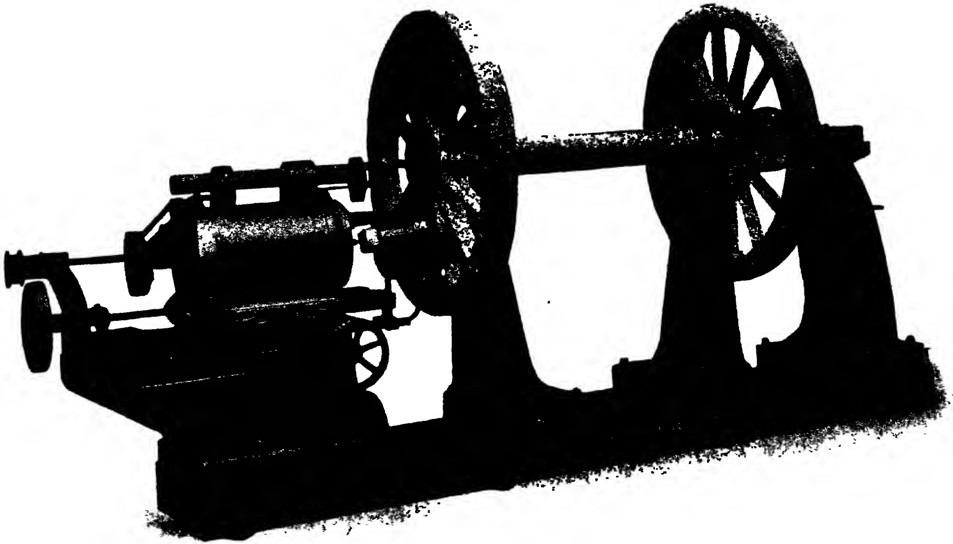


FIG. 490.—Crankpin Grinding Machine.

of eccentricity is variable while the machine is running, and by this means the grinding wheel is brought up to or away from the work being ground. The head has longitudinal traverse motion on the bed, controlled by sensitive gears and stops.

Two supports are provided for carrying the locomotive wheels and axles: these have vertical adjustments by screw gearing; they can also be moved along the bed by means of rack gear.

The cranks are accurately quartered: at the grinding head by a pin which enters the turning centre of the crankpin to be operated upon; the other crank being centred by a pin at right angles to that in the grinding head, located on the tailstock.

The wheels and axles are set level by means of poppets on the grinding head and tailstock, as in a wheel lathe. The machine can be driven by means of a belt or an electric motor drive and requires 7½ H.P.

Turret Grinding Machines

This type of machine is of special interest, as it represents one of the latest developments in grinding practice. The machine illustrated in Fig. 491 is manufactured by Messrs The Churchill Machine Tool Co., Manchester, and bears much the same relation to the plain or universal grinding machine as the turret lathe does to the ordinary sliding, surfacing, and screw-cutting lathe. It is designed to carry three abrasive wheels, two of which may be heavy wheels for external work and the third for internal grinding.

The advantages of a machine of this character will be obvious to all grinding operators who are familiar with the universal type of machine. It eliminates the time spent

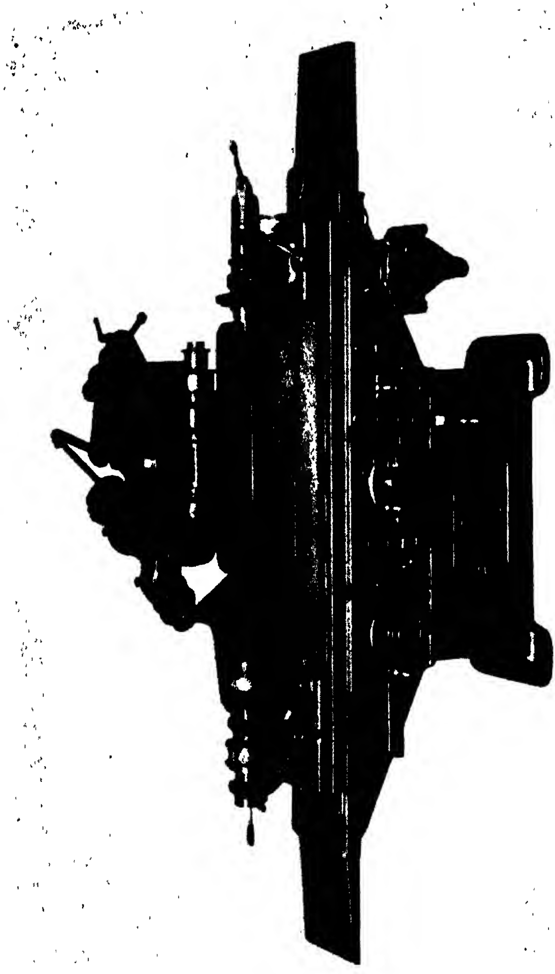


FIG. 491.—Churchill Turret Grinder.

in changing from external to internal grinding, and the lengthening and shortening of belts, and ensures that the various ground surfaces are in correct relationship with one another.

The main spindles are primarily intended to carry a disc wheel for cylindrically grinding shafts and other pieces of work, and secondly, a cup wheel for side or face grinding of flanges or similar work. On jobs where the cup wheel is not required it may be removed and a disc wheel substituted of the same size as that carried on the first spindle, thus enabling the use of roughing and finishing wheels on work where a high finish is required, as in gauge work, instead of using one wheel which may not be best for either purpose. On the other hand, wheels of different grades may be carried for the grinding of different metals, obviating the changing of wheels and consequent loss of time and waste of wheel in retruing.

The size of the machine illustrated is 16 in. by 36 in., and the maximum swing is 16 in. The greatest external diameter that can be ground when using a 12-in. wheel is 12 in. Eight work speeds are provided, four when using the live spindle, and four with the dead centre. The table has eight speeds, and the top table can be swivelled to an included angle of 9°.

On chuck work the tailstock can be removed and the machine operated purely as a chucking machine. The work headstock carries a hardened and ground spindle, and has a swivel base graduated in degrees. Various attachments are supplied with the machine, and the equipment includes a face plate, four-jawed chuck, and a face chuck with draw-back collet.

An example of the class of work done on this type of machine is shown in Figs. 492 and 493. In Fig. 492 the

bottom face and edge of a ball-bearing housing is being ground, and in Fig. 493 the same piece of work is being

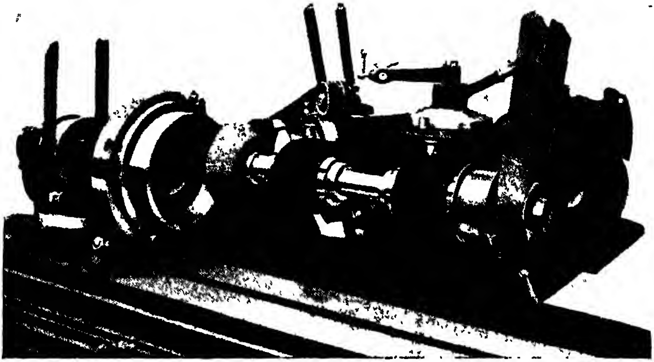


FIG. 492 —Face Grinding on Turret Machine.

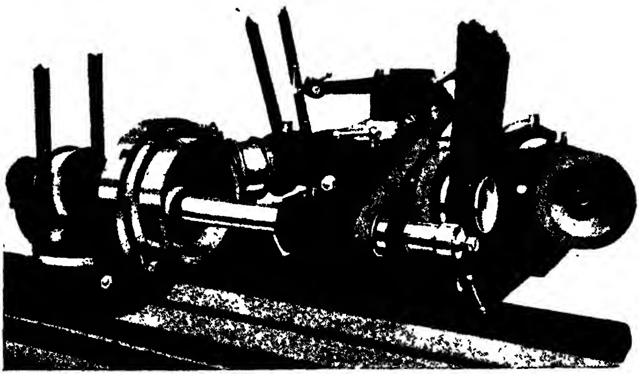


FIG. 493.—Internal Grinding on Turret Machine.

ground internally at the same setting, the turret being turned in order to bring the internal grinding spindle into position.

Pendulum Grinders

The machine illustrated in Fig. 494 has been specially designed to deal with locomotive work. It is constructed

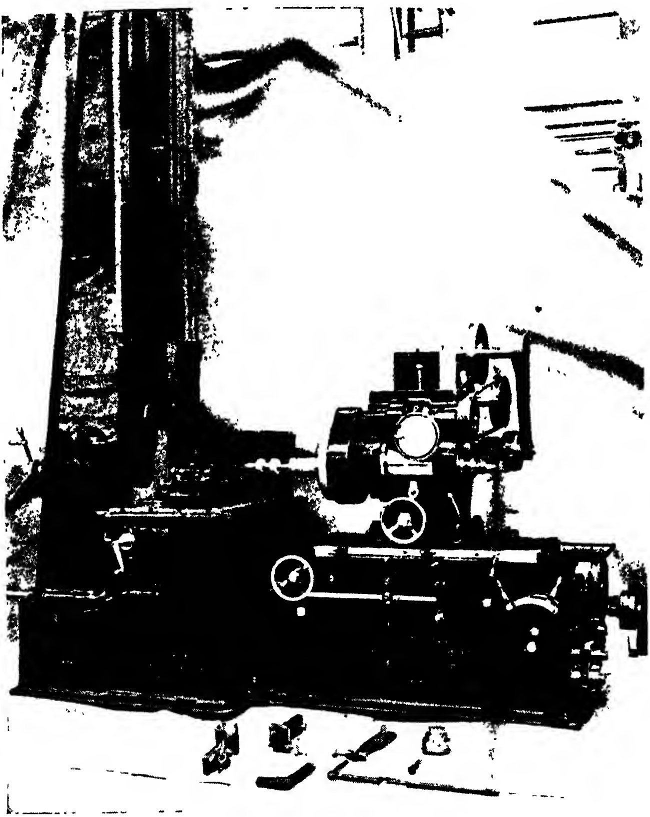


FIG. 494.—Pendulum Grinder.

by Messrs The Churchill Machine Tool Co., and is capable of grinding any normal expansion link both in slots and holes, and when the pendulum link grinding

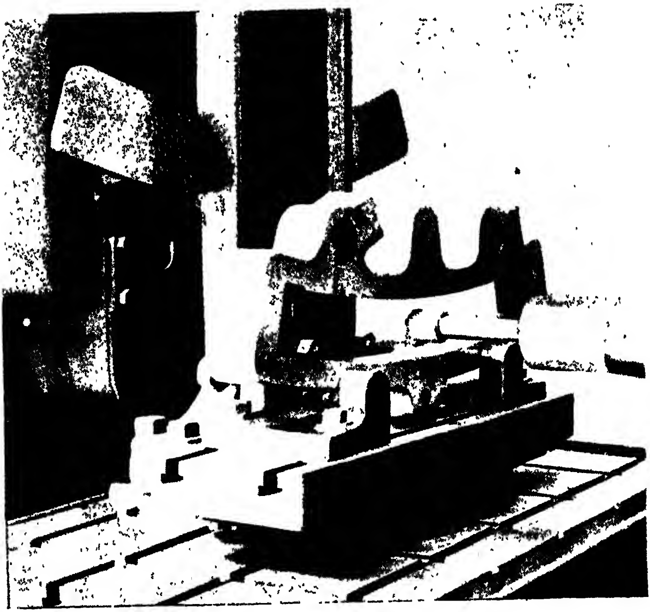


FIG. 495.—Pendulum Grinding Operating on Expansion Link.

mechanism is swung out of the way the machine can be used for grinding cylinders, sleeves, bushes, and general cylindrical work.

The machine illustrated has a normal capacity for cylinder grinding of 14 in. by 18 in., with a vertical adjustment of the grinding wheel of 10 in. For surface

grinding the automatic cross feed of the table is 30 in., and the maximum width of work 18 in., the number of table speeds being four.

The maximum radius for link grinding is 84 in., and the minimum 42 in. The greatest length of slot that can be taken is 24 in.

This machine is manufactured with a countershaft, or single pulley, or direct coupled motor drive, and various sizes of detachable spindles are used to suit the requirements of the job. A close-up view of an expansion link in position is shown in Fig. 495. A special fixture for holding the link is bolted to the table of the machine.

Automatic Radial Grinding Machine

An automatic radial grinding machine intended for such work as ball-bearings, thrust washers, and spherical joints is shown in Fig. 496. This machine is constructed by Messrs Jones & Shipman, Leicester, and the work done is finished without the necessity of subsequent lapping, and satisfies the exacting requirements of accuracy and mirror-like finish of ball-bearing housings.

The radial arm carrying the work head is pivoted on ball journal bearings, the weight of the oscillating parts being supported by adjustable ball-bearings having three-point contact with a hardened and ground steel race way. Provision is made to instantly start and stop the automatic oscillations independent of other movements; the radial oscillations are graduated in degrees for setting the position or field of operation.

The distance from the centre of the oscillating head to the centre of the pivot of the diamond truing device is the same as the swing set piece located at the right-hand

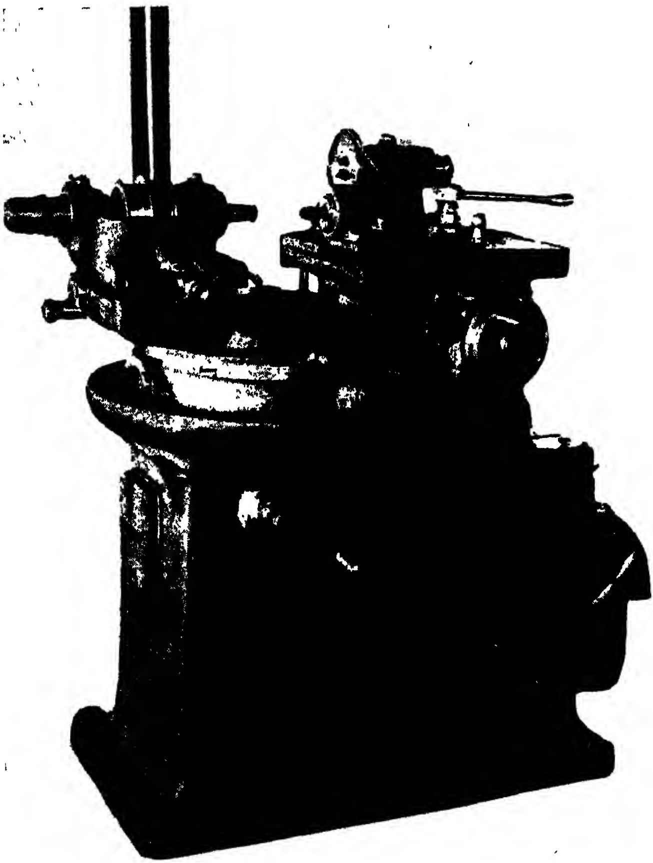


FIG. 496.—Radial Grinding Machine.

end of the machine. When truing the wheel the distance piece is inserted between the end of the stop screw and the face; it is then ready to be trued. After removing the distance piece, the slide is brought up to the end of the screw stop and the machine is set.

Two sizes of this machine are manufactured, one with a $1\frac{1}{2}$-in. spindle and the other with a 2-in. spindle. The machine is provided with work-head spindle speeds of 90, 141, 202, and 276 revolutions per minute. The work-head spindle has a longitudinal traverse of $5\frac{1}{2}$ in., and a cross traverse of $4\frac{1}{2}$ in., with a maximum swing of 15 in. diameter and 28 oscillations per minute. The wheel spindle is provided with four speeds. The wheel-head has a longitudinal traverse of 8 in., a cross traverse of $5\frac{1}{2}$ in., with a minimum cross feed of 0.0001 in. per stroke.

Grinding Wheels

The production of grinding wheels is a specialised business and there are available many different grades and forms suitable for any work or material. As one would expect, the makers are always willing to advise on the grade of wheel to use and the important matter of grinding speeds. The grade of a wheel has no direct relation, so to speak, to the finish of the ground surface. A very fine surface can be obtained with a relatively coarse wheel provided that the grade of the wheel is properly related to the surface speeds of both wheel and work. These facts only become apparent after considerable experience at the grinding table. For instance, when rough grinding the cutting particles are being constantly worn away from the bonding so that the face of the wheel is kept rough and sharp and the ground surface will be

comparatively rough. Then, after the wheel has been trued by the usual diamond tool, light finishing cuts in conjunction with a reduced work speed will give a smooth finish, except in the case of brass or soft bronze, where the grain of the wheel must be as fine as the finish desired.

As already stated, all grinding work is done at a high peripheral speed between 4,000 and 16,000 ft. per minute, according to the type of wheel, and with a work speed ranging round 20 to 60 ft. per minute. The general practice is to rough grind with a fairly soft, coarse, free cutting wheel and a comparatively slow work speed in conjunction with a coarse side feed. Finishing operations are then done with a harder and more compact wheel, though this can only be regarded as a general rule and in production work experience alone is the best guide. The term "grade," as applied to a grinding wheel, refers to the tenacity with which the bonding material holds the cutting particles or abrasive grains in place and not to the hardness of the abrasive. A wheel from which the abrasive grains can easily be dislodged is called "soft," or of "soft grade," and one which holds the grains securely is referred to as a "hard wheel." By varying the amount and composition of the bond, wheels of different grades are obtained. The grain or coarseness of a wheel is designated by numbers, which indicate the number of meshes to the inch through which the kernels of the abrasive material will pass. For example, a 36 grain means that the abrasive will pass through a sieve having 36 meshes to the linear inch. The method of grading wheels adopted by different manufacturers is given in their lists, and now conforms to a standard procedure.

The grade and grain to use depend upon the kind of material to be ground, its degree of hardness, and the surface area in contact with the wheel. Theoretically, a

wheel is of the proper grade when the bond is just hard enough to hold the abrasive until it becomes too dull to cut effectively; then, because of the increased friction, the dull grains are torn out and new points come into action, so that the wheel automatically sharpens itself. The harder the stock being ground, the more quickly the grains are dulled; hence, as a general rule, the harder the material the softer the wheel, and vice versa, although some very soft materials, such as brass, are ground with a soft wheel which crumbles easily and does not become "loaded" or clogged with metal. When a hard wheel is used for grinding hard material the grains become dulled but are not dislodged as rapidly as they should be; consequently the periphery of the wheel is worn smooth and becomes glazed, and excessive pressure is required to make the wheel cut. Any undue pressure tends to distort the work, and this tendency is increased by the heat generated. If the surface of the wheel becomes loaded with chips and burns the work, even when plenty of water is used, it is too hard.

CHAPTER XXIII

DROP FORGING AND STAMPING

ALTHOUGH drop forging became fairly common practice in the railway shops around the year 1900, it is principally in connection with the production of general machine parts, and more particularly with those produced for the motor industry, that present practice has been evolved on a large scale. As pointed out by Mr E. S. Brett, who has been associated with this class of work since its inception:

> "It is by means of dies that properly formed forgings are to be obtained, and the main thing which comes within the province of the engineer is to provide for the forger a suitable form of power for actuating the dies or tools, having in mind that the plastic or forgeable condition of wrought iron or steel when obtained cannot be retained beyond limited periods, especially in the case of articles having thin or light parts, when its duration is very brief. This power must be capable of instantaneous application; it must be simple and ample, and the essential feature for producing the proper effect is that it must be of the same kind as the smith, with his limited physical strength, produces with hand, hammer, or sledge; that is to say, a perfectly elastic blow of sufficient force to produce an immediate and substantial effect upon the material."

Materials—Heat Treatment

A large number of the steels now used in present-day production are suitable for drop forging in accordance with the instructions of the steelmaker. The object of drop forging is to produce a part in the rough which, in the first place, shall require the minimum of machining, and secondly, be in such a condition as regards the fibres to give it the maximum strength; and heat treatment is an important part of the work in connection with the production of good forgings, and this is especially the case with alloy steels.

The latter have to be dealt with in accordance with the steelmaker's specification, but it is straight carbon steels which are the most generally used for the present purpose. There are two critical points in the temperature to which the steel is heated which have a great effect on the molecular structure of the material. These might be called the maximum and minimum points. The ranges of temperature at which the structure of the steel changes vary, of course, according to the chemical analysis of the steel.

Most drop forgers when put to work on a stamping proceed on the practice that it is desirable to heat the metal to as soft a degree as possible, the object being that it will more readily flow into the impression, and that they will be able to produce the finished job in the fewest number of blows and so obtain quick output.

This is frequently desirable and necessary; in fact, under ordinary stamping practice the article when it leaves the dies will be very hot, and the steel will be in a more or less bad condition. What has happened is that in heating the material the crystals have grown or expanded and have only partially gone back to fine

structure. Sometimes, taking an exaggerated case, the steel becomes actually burnt; that is to say, fused. This fusing takes place around the margin of the enlarged crystals. An oxidised film is thus formed which tends to separate the crystals from each other, and the material becomes actually split up into a larger number of separate units. This separation of the crystals in the case of burning is permanent and no amount of forging will correct it.

But with the ordinary stamping, heated within reasonable limits, the material can be corrected if subjected to heat treatment, which consists briefly of reheating the stamping up to a temperature varying according to the carbon of the steel; in the case of carbon steel of about 0.25, this would be heated up to about 820° C. and then plunged into whale oil. This fixes the structure of the steel when it is in its best possible condition, the crystals being split up in the smallest form. Obviously a stamping thus treated will give very much improved results.

Another aspect of heat treatment is that it tends to release the strains set up in the actual process of drop forging. It should be recollected that in contradistinction to ordinary forging the flow of material in a drop forging is complete and not only on the surface. In forming intricate shapes, very often strains are set up which are released by heat treatment.

In the case of higher carbon steels still further improved results can be obtained by tempering; that is to say, after heat treatment the stampings are again reheated to a temperature of about 650° C., laid in the air, and allowed to cool off.

By way of emphasising the importance of this process, data showing tests before and after heat treatment are given.

MATERIAL USED—MILD STEEL, CARBON, 0.25 PER CENT.

Test taken before heat treatment:—

Tensile . . .	28·8 tons per sq. in
Elongation . .	36 per cent.
Izod impact . .	28 ft.-lbs.

Test taken after heat treatment, *i.e.*, heating up to a temperature of 810° C., plunging in whale oil, taken out and allowed to cool:—

Tensile, increased to	33·8 tons per sq. in.
Elongation . .	33 per cent.
Izod impact . .	81 ft.-lbs.

It will be noted that the elongation is a little less in the heat treatment test, but the tensile is much higher, and so is the Izod impact (or toughness test). It will be obvious that this is a much better steel for working purposes.

The importance of this matter of heat treatment cannot be over-estimated. Drawbar hooks, for instance, are in the majority of cases used without any further treatment. Owing to one or two breakages having occurred, due probably to this question of the enlarged crystals, nickel steel has been specified. It will be obvious, however, that correctly heat-treated drawbar hooks in straight carbon steel should meet all requirements.

Furnaces—Advantages of Coal

Whilst the gas-fired furnace dealt with in an earlier chapter is probably the best for average work, some drop forgers are of the opinion that the gas flame lacks the necessary penetrative power in this connection, while at the same time being somewhat severe on the outside. Coal or oil furnaces are often recommended.

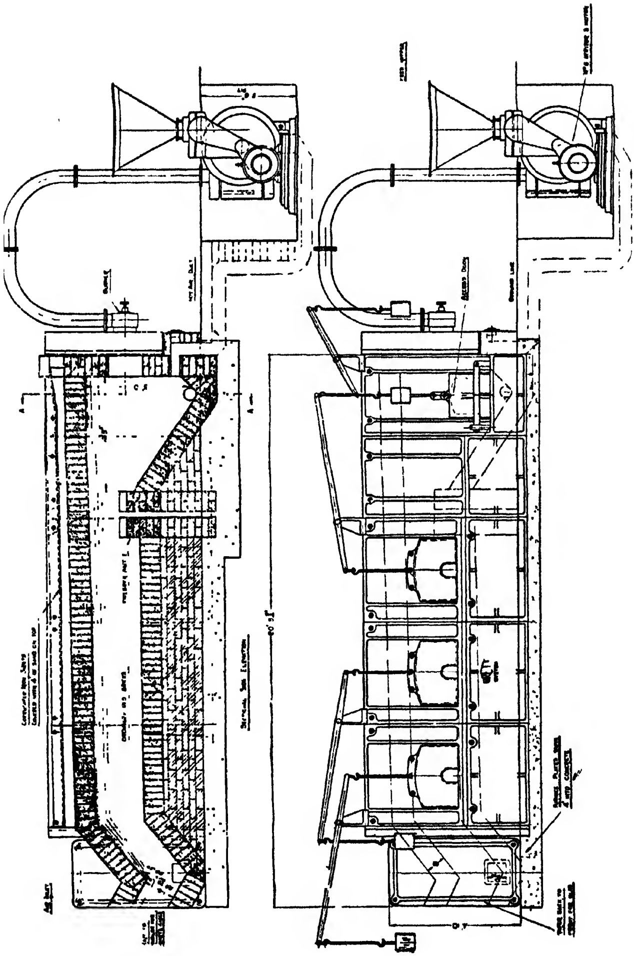


FIG. 497.—Pulverised Fuel Furnace.

The oil-fired furnace is compact, clean, and easily operated. It can be recommended for small shops, but when a large amount of work is being done the pulverised fuel furnace, as shown in Fig. 497, is regarded as the best all-round proposition. The average working temperature is about 1,300° C., and with the waste heat leaving at about 600° C. there is a good opportunity for generating steam from it. It must always be remembered that the requirements of drop forging are peculiar to the work, and especially to the care which has to be given to the proper heating of each piece, which is somewhat against the economical operation of the furnace. In consequence, the relatively cheap working of the pulverised fuel furnace is an advantage here. It can use cheap fuel and can give the same amount of heat with about 25 per cent. less coal than would be required in the orthodox type of coal-fired furnace, in addition to providing steam for working hammers.

Equipment for Production

Die Cutting.—Obviously drop forging is not an operation which will pay unless a fairly large number of similar parts are being put through the shops, on account of the cost of the dies. In this connection, therefore, it might be well to mention a comparatively new machine introduced into this country by the American concern of Pratt & Whitney. While not a die-sinking machine in the accepted sense of the term, it is used to a large extent for the rapid and cheap production of forging dies. Shown in Fig. 498, this Keller automatic tool-room machine is really a special and unusually powerful milling machine operated by a simple electrical control. By means of this control the shape of a master is

FIG. 498.—Keller Die-sinking Machine.

reproduced automatically by the machine. The job may be either profiling in two dimensions or a solid form requiring three-dimension cutting. In each case a tracer

passes over the master form and the cutter duplicates its path precisely. The cutting is controlled electrically to maximum cutter capacity regardless of the shape being duplicated.

The master forms used can be very simple. Light metal templates are sufficient for the heaviest contouring jobs. Solid masters may be wood or cement, or they may be finished tools which must be duplicated. Worn or broken dies can be used as masters and replaced directly with great economy.

The accuracy of work produced on this machine is such that frequently very little or no hand finishing is needed. Also, in most cases it requires much less time to bring a job to the final finishing stage than it would take for roughing alone on a hand-operated machine. In addition, several operations may be performed on the same machine, frequently with one set up. For example, a die impression can be cut and holes bored or plugs set accurately in relation to that impression. A forging die cavity may be cut with the die mounted on the fixture, and then the edger can be cut automatically simply by laying the die on its back.

A feature which is unique in the Keller machine is the automatic operation of the cutter under tracer control. In addition, all movements may be operated either manually or electrically by switches from the control cabinet. Two methods are used in setting up a job or in plain milling or boring.

The tracer is mounted on a bracket above the cutter and the distance between the two is adjusted properly for the job to be done. From then on the tracer and cutter move in unison. The tracer follows the shape of the master form and the cutter duplicates that shape in the work. This is done by a very light tracer

contact and electric control, so that reproduction is very accurate.

There are two major types of operation under tracer control. The first of these is known as the "contouring operation." In this the tracer guides the horizontal and vertical movements of the machine, the cutter having been set to a given depth before the job is begun. The tracer point is in continuous contact with the master, always seeking the edge and never breaking through. A movement of less than 0.001 in. on the tracer point will vary the motion of the machine. The sensitivity is independent of the size of the mill, of the depth of cut, or the hardness of the material. There is no cam action on the master. The tracer takes its impulses from light mechanical contact on its point, which it transforms into electrical contacts which energise and de-energise the magnetic clutches that drive all the movements of the machine. In contouring work the operator need only watch the job to establish the general bias of the machine as it travels around each 90°. This type of operation is employed in the production of blanking dies and punches, trimming dies and edgers for forging dies, piercing and extrusion dies, cams and templates.

The second type of tracer control is fully automatic. The horizontal and vertical movements are set so that the machine automatically travels in one direction and feeds over in the other at the end of each stroke. A different type of tracer from that employed in the contouring operation is used to control the transverse movement of the machine.

This tracer continuously seeks contact with the surface of a solid master, and as the automatic travel and feed causes the cutter to cover the entire surface, any shape will be produced.

Equipment for Production

Hammers.—The drop hammer, as shown in Fig. 499, at the instance of Bretts Patent Lifter Co., is the machine which provides the blow which, while elementary, is from the drop forger's point of view the most potent. The modern drop hammer is designed from the result of years of experience with a definite object in view. The lifter has to control the live weight of the hammer in a manner suited to the work, while equally important are accuracy and strength of the guides. Of the lifter, which may be steam, compressed air, or motor-driven, far more is required than to simply lift the hammer and allow it to drop. It must have a super-abundance of power over the live weight which it has to control.

The blow of an efficient drop hammer is like the cracking of a whip. The power of the lifter must be such that the operator can obtain the sharp elastic "snappy" blow which is only possible when the lifter is so well over its work that immediately the blow is struck the hammer is on the move again with not the slightest suspicion of what is known as "dwelling on the dies." Blow, rebound, and lift are almost instantaneously merged together.

For large drop hammers the steam or compressed air lifter, as constructed to-day, is difficult to beat. Its construction, as shown in Fig. 500, indicates the main working principle.

The feature of this lifter is the very direct and at the same time very flexible application of the compressed air or steam to the mainshaft controlling the hammer. Also, if the hammer or tup has to be suddenly arrested owing to the stamping moving in the die, there is no shock created in the mechanism which absorbs the inertia

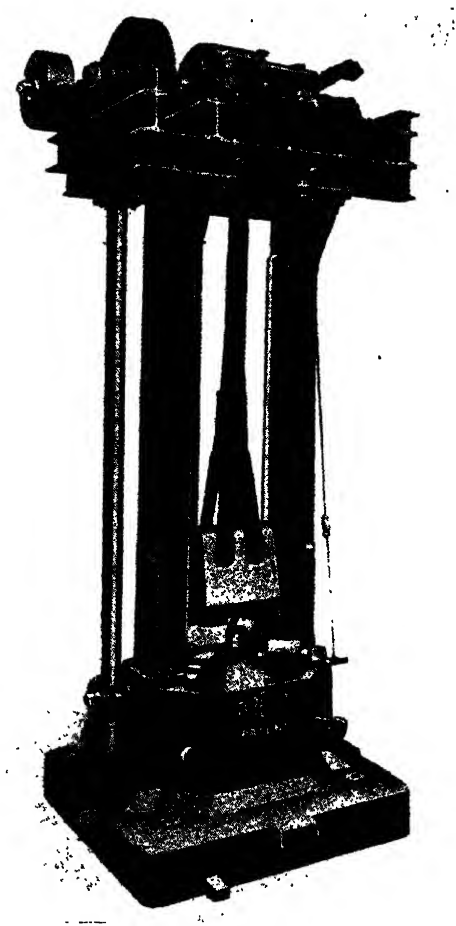


FIG. 499.—Drop Hammer.

of the hammer, with steam or compressed air at the back of the wing. The modern steam or compressed-air lifter

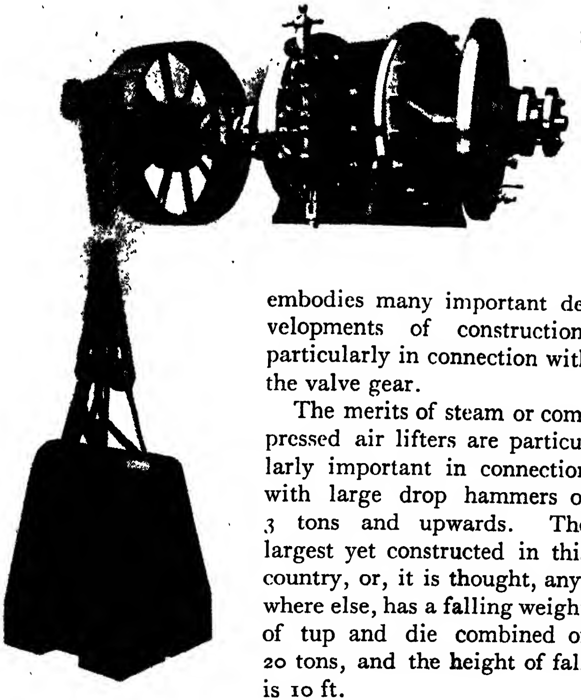


FIG. 500.—Drop Stamp Lifter.

embodies many important developments of construction, particularly in connection with the valve gear.

The merits of steam or compressed air lifters are particularly important in connection with large drop hammers of 3 tons and upwards. The largest yet constructed in this country, or, it is thought, anywhere else, has a falling weight of tup and die combined of 20 tons, and the height of fall is 10 ft.

The actual blow by a hammer of this class striking a stamping with a penetration of $\frac{1}{32}$ in. may well be over 70,000 tons. An alternative type which is often convenient and economical to install is the friction or motor-

driven type. These friction lifters, which have been operated for many years, take the form of a clutch which has a very strenuous duty to perform as its working effect is achieved by two surfaces rubbing together. The hammer is suspended in the slides entirely by means of a slipping effect; but the construction has been developed over many years and they are a good proposition for hammers of quite considerable size. This type of lifter is fitted to the machine previously shown, and its main feature lies in the ferrobestos linings on the friction blocks which are readily renewable; also, owing to the inclined friction surface, the lubricated effect can be maintained without loss of efficiency and a corresponding reduction in wear. A circulation of cold air around the friction drum created by vanes ensures a cool effect, but water cooling may also be employed.

In the construction of the hammer itself the base block and the guide rods of a modern mass-production machine form one homogeneous and solid unit. The guide rods are of heavy reinforced section, having tongues which extend into grooves in the base block.

Hammers of this type are really essential for accurate work of any class, and especially for stampings of intricate shape which tend to create a "kick" or side shock; also, they are particularly necessary for multiple impression dies. There is no doubt that the most economical method of producing stampings required in considerable quantities is to design the dies so that the stamping is produced outright under one hammer, direct from the billet.

The application of this system of multiple die stamping is desirable with a very large number of stampings. The usual type of drop hammer, which has guide rods held in position by means of adjusting pins and nuts, will not

stand up to the strenuous duty that is put upon it when multiple impression dies are used.

Another point in connection with the production of good work of this class is that of producing a forging to fine limits of weight and dimensions, connecting rod forgings for the automobile trade, for instance, being now produced to specified dimensions within $\frac{1}{1000}$ in. and $1\frac{1}{2}$ per cent. in weight. On the other hand, for comparatively rough work the drop-board hammer is frequently installed. It is very simple in working and is extensively used in America. Connected to the tup is a specially prepared board of hickory wood which has leather insertions to give elasticity. This board is about 9 ft. long and is placed between two rollers which revolve in opposite directions. When these rollers are brought together the board is gripped and the hammer lifted. The working is as follows: the hammer is suspended by a grip motion which holds the board. When the operator depresses the treadle the board is released and the hammer falls. In doing so it releases the hold up for the friction bar, and just at the point of impact the friction bar comes into operation and picks the hammer up. At the top of the stroke, whatever this may be (it is adjustable), the knock-off lifts the friction rod, which is suspended until the hammer falls. As long as the operator keeps the treadle depressed the hammer delivers blows with great rapidity. When the treadle is released the hammer rises and stops.

Principal Features of Modern Friction Drop Stamp

The principal features of a modern friction drop stamp, as made by Messrs B. & S. Massey & Co. Ltd.,

Manchester, are shown in Fig. 501, and while steam drop stamps may be preferred in some instances, the

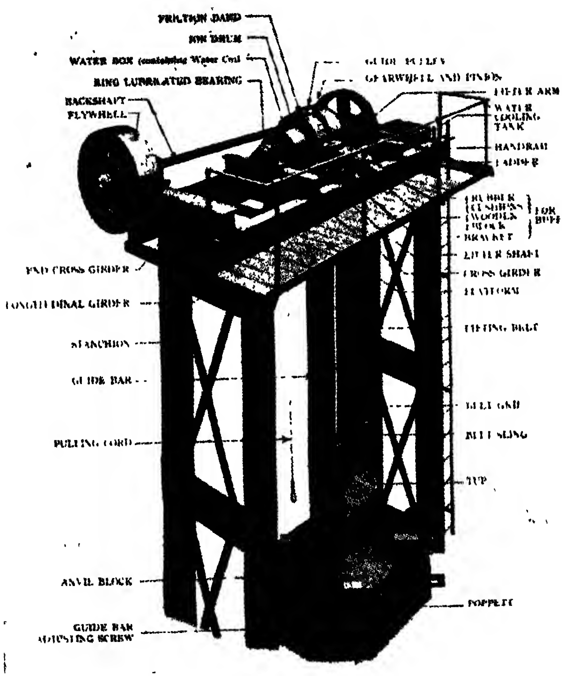


FIG. 501.—Typical Drop Stamp (Massey).

majority now installed are of the friction lift type, for the simple reason that they are much cheaper to run even though the waste heat recovered from the furnaces may appear the ideal means of working the hammers. As a

matter of fact it is more economical to put in modern recuperative furnaces which do not produce an excess of waste heat. So far as construction is concerned this is made amply clear by the previous diagram, but in respect of the principal parts and method of operation one important point is the lining up the lower die with the top one. This is done by the screw and poppet arrangement indicated at the base, there being as a rule four poppets, and the die, for preference, is keyed on to a dovetail in a special die-holder itself. The purpose of the die-holder is to protect the surface of the anvil block from damage by small dies. Where possible the poppets are made with square shanks to prevent turning, but when the anvil blocks are of steel the poppets are made with circular shanks and eccentric spigots under the head. In the larger stamps the thread for the poppet screw is cut in a separate nut which can be easily slipped into or out of its place in the poppet head.

Attaching and Guiding of Tup

Ropes were at one time regularly employed for attaching the tup to the lifter arm, but hair belting is now often used for this purpose, having been found by experience that though higher in first cost it has a considerably longer life and is more economical. The belt is looped round the pin of the lifter arm and can be attached to the tup in two ways.

The guide bars normally provided are made from rolled steel billets and, unlike cast-iron guide bars, they are practically unbreakable. In stamps of 20-cwt. size and larger (except preparing stamps) each guide bar has two planed vee slides for guiding the tup. The tops of the

guide bars are held in position by housings in the girder-work, where they are secured by wooden wedges and hair-belt packing. The lower ends rest in tapered recesses in the anvil block and are adjusted by screws.

In other cases, often where the stamps are erected on batteries, there are rigid guides of cast steel which are fixed firmly to the anvil block and are quite independent of the overhead structure. They have double-vee slides for the tup and are adjustable both at the foot and at the top to take up wear. This arrangement is particularly useful where multiple impression dies are used, the double-vee slides and the rigid guiding of the tup ensuring the accurate die alignment necessary under such circumstances. Moreover, the extent of the adjustment—over ½ in. on each guide or 1 in. total—is of real practical value and allows of replaning the tup and slides.

In respect of the lifting mechanism, when the pulling cord is pulled the friction band is tightened and made to grip the revolving drum. The lifter arm being connected to the band, rotates with it and lifts the tup. When the cord is released the spring disengages the band from the drum and the tup falls freely.

The cord is wound round the capstan bush in the direction in which the shaft and bush revolve, and the effect of any pull on the cord is therefore increased by the friction of the revolving bush. Moreover, as the arm rotates in the lifting direction, carrying the cam lever with it, the cord is automatically unwound and the tension on it relieved. It is therefore necessary to maintain a constant pull on the cord in order to keep the band tight and so prolong the rise of the tup. If the cord is pulled to a certain point and then held stationary, the friction of the band is at once reduced until it is just sufficient to hold the tup suspended and no more. In

this way a very intimate relationship is established between the movements of the tup and of the operator's hand, and the control thus obtained is exceedingly simple, sensitive, and reliable.

One-Man Operation—Massey's Simplex Gear

The Massey "Simplex" automatic gear makes a friction drop stamp essentially a one-man machine. The stamp can, if desired, be controlled by hand by a driver, but when the automatic gear is in action the stamp is actuated by the stamper himself by a foot lever. While this is held down the tup rises and falls automatically, giving a series of blows of equal force. The upper limit of the stroke can be adjusted to give the blow required and the "pick up" at the bottom to suit the thickness of the dies in use.

When the foot lever is released the tup rises to the top of the stroke and is held there without consuming any power. The force of the blow may be modified by raising the foot lever slightly, thus allowing a drag as the tup falls. "Single" blows are obtained by releasing the foot lever immediately the blow has been struck.

For certain classes of stampings it is essential, if a high production is to be obtained combined with low running costs, that the stamp shall be automatic in its action and under the control of the stamper himself. These features are, of course, available in a board drop stamp, but they are there associated with some very undesirable features—noise, trouble in adjusting stroke, and heavy upkeep costs.

Stamps of the battery form, as built by Massey's, up to 30-cwt. or 40-cwt. size, and all stamps of the self-

contained form, can be arranged with automatic gear in addition to the hand control.

The stamp is regulated by two hand levers which determine the length of stroke and the quality of the blow, and by a foot lever which actuates a hold-up gear. When the automatic gear is put into action the tup rises to the top of the stroke for which it is set by the outer hand lever, and is held suspended there by the hold-up brake without consuming power.

On depressing the foot lever the hold-up brake is released and the tup falls. The inner hand lever is set so that the tup is automatically lifted again at the correct moment to suit the type of blow required and the thickness of the dies in use. So long as the foot lever is held down the tup continues to rise and fall, and the length of stroke and character of blow can be altered by means of the two hand levers without stopping the stamp.

Single blows can be obtained by holding the foot lever down long enough for one blow to be struck and then releasing it. Alternatively, the automatic gear can be put out of action and the stamp can then be driven by hand in the ordinary way.

As regards the mechanism, referring to Fig. 502, the trip rod F is flexibly attached to the lifter arm and reproduces the movements of the tup on a small scale, its maximum travel being only a few inches. The spring P presses down a rod D which is attached to the pulling cord. The lower end of this rod D passes between four guide rollers and is then connected to a toggle mechanism which, when in the position shown, prevents the spring from tightening the pulling cord. When the trip rod F pulls, the collar Z strikes the lip U of the upper toggle lever, forcing the centre joint away from the stop X and

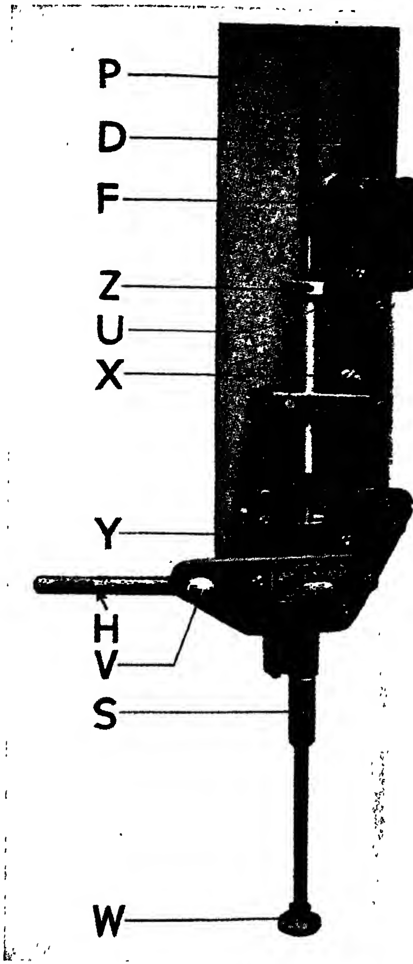


FIG. 502.—Drop Stamp Mechanism (Massey).

thus allowing the spring P to come into action. As this takes place the rod D is pressed down, thus pulling the cord and causing the tup to rise; whereupon the trip rod F is also lifted and the cam Y, the back of which is supported by two thrust rollers, engages with the roller on the toggle mechanism and restores it to the position shown.

When starting up the stamp and when working by hand, the toggle mechanism may be locked in the position shown by means of the hand lever H and the stop V, thus preventing any automatic action. When working the stamp automatically the hand lever H is kept above the stop V.

The height from which the tup falls is determined by the position of the sleeve S, which is arranged on an interrupted thread on the trip rod so that a quarter turn of the sleeve enables it to slide up and down into any desired position. A spring catch within the sleeve locks it after it has been given a quarter turn back on to the threads. The cam Y is loose on the trip rod so that it is lifted by the sleeve S wherever this is fixed and falls by its own weight, a stop being provided to prevent it falling below its guide plate.

Adjustment for the bottom of the stroke, *i.e.*, for the "pick up," is effected by means of the knob W, which screws the collar Z up or down the upper half of the trip rod, thus regulating the point at which the collar strikes the lip U.

The automatic gear is provided with grease-gun lubrication and has few wearing parts, any of which can, if necessary, be easily and cheaply replaced.

The Friction Lifter—Hold-Up Gear

This is shown in Fig. 503. It comprises a constantly rotating drum *a* around which is a lined steel band *b*.

This is anchored at one end *c* to a stud in the lifter arm *d*, while the other end *e* is carried by a camshaft running through the lifter arm and actuated by the lever *f*. To this lever is attached the pulling cord *g*, which passes

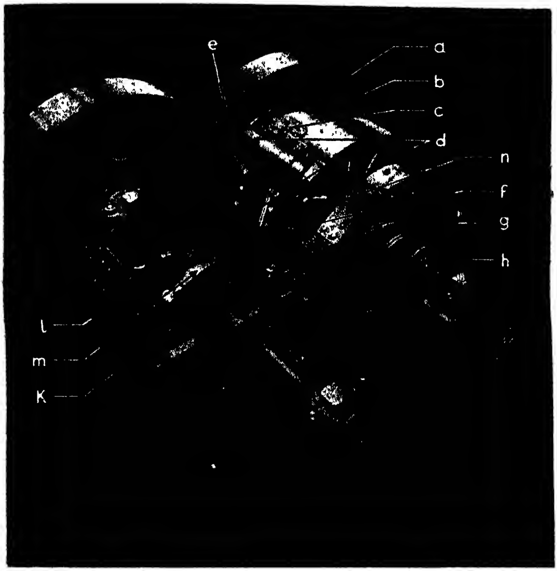


FIG. 503.—Drop Stamp Friction Lifter.

around the capstan bush *h* attached to the lifter shaft and down to the operator. When the cord is pulled it tightens on to the rotating capstan bush, rotating the lifter arm and so lifting the tup by means of the belt *k*, the guide pulley *l* keeping the upward pull vertical. A buffer arm *m* provides a stop for the arm in its extreme

position at either end of the stroke. The spring *n* ensures a free fall by disengaging the friction band on the pulling cord being released.

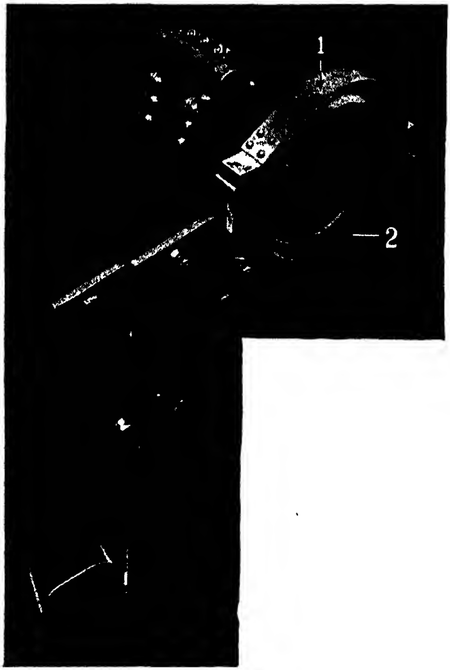


FIG. 504.—Drop Stamp Hold-up Gear.

It is necessary to maintain a constant pull on the cord in order to keep the band tight and so prolong the rise of the tup. If the cord is pulled to a certain point and then held stationary, the friction of the band is at once

reduced until it is just sufficient to hold the tup suspended. When worked by hand a very intimate relationship is established between the movements of the tup and of the operator's hand, and the control thus obtained is exceedingly simple, sensitive, and reliable.

For the automatic action an auxiliary pulling cord is provided to which the rod *d* (Fig. 503) is attached, pulling and releasing the cord at the dictates of the automatic gear in exactly the same way as the operator pulls and releases the hand pulling cord.

The hold-up gear shown in Fig. 504 is an essential element of the automatic action, and the foot lever which actuates it is that by which the operator controls the stamp.

A friction band 1 encircles a ring 2 cast solid with the lifter arm, and is so arranged that movement of the lifter arm in the falling direction makes the band grip the ring, whilst lifting is unimpeded.

By pressing down the foot lever the band is opened and the tup allowed to fall. When the foot lever is released the tup rises freely, but immediately it begins to fall, causing the lifter arm to rotate in the falling direction, the band grips and the tup is held suspended.

A machine known as a double swage hammer is shown in Fig. 505. It is a type of machine used to some extent in Germany for the production of drop forgings, and it can forge small automobile crankshafts in two bending blows and about six swage blows at one heating, with an output of 30 to 40 per hour. It has the advantage of low first cost both for machine and foundations.

Operating a heavy drop hammer with an anvil block involves appreciable risk. The foundation may subside, a complete renewal of the foundations is no rare occurrence, and the danger of a fractured anvil has

always to be reckoned with. One of the most serious difficulties is the effect of the constant vibration on the soil, which usually results in more or less damage to the masonry and buildings.

The novelty in operation consists in the arrangement of two tups (rams) of the same weight striking against each other at the same speed, which thus completely does away with the necessity of anvil blocks. Hammers of this new type are no more than about one-quarter to one-third the weight of hammers of the same efficiency

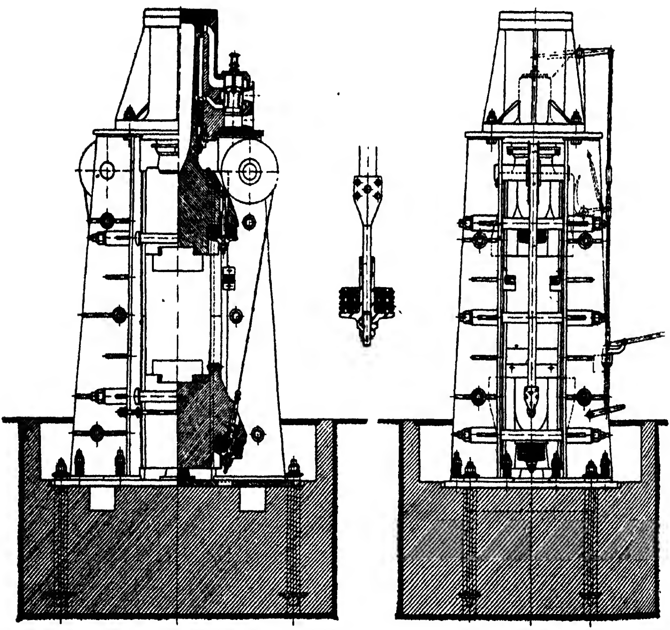
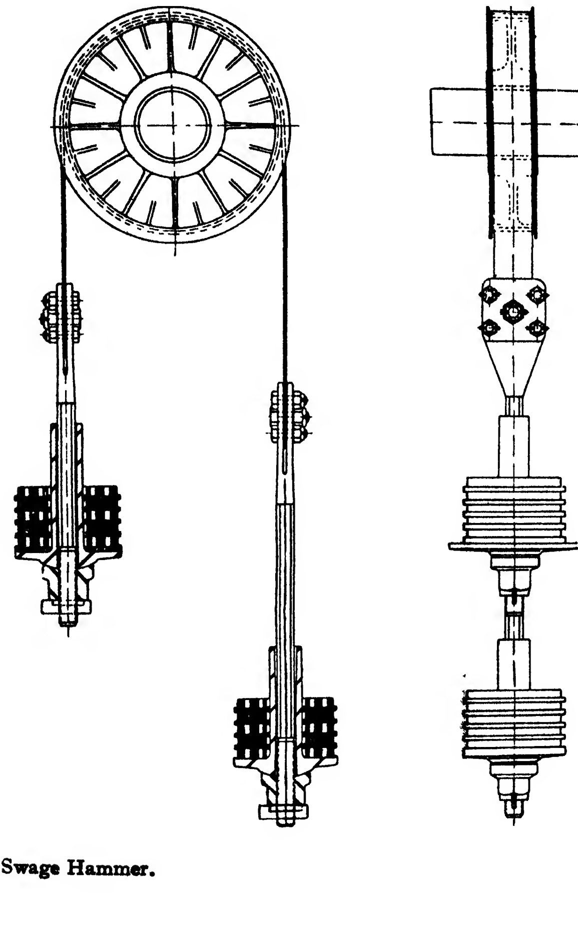


FIG. 505.—Double

which strike on an anvil block. A double swage hammer with an effective blow of 181,000 ft.-lbs. weighs no more



Swage Hammer.

than about 95 tons complete, which is only about three-tenths of the weight of the aforementioned steam drop hammer with a 12-ton tup and anvil block.

This type of hammer calls for nothing more than a light foundation, because the ground is subjected to no impact and that required is not more than about one-eighth of that necessary for the hammer and anvil of the more usual type. Referring to the diagram, the drive, whether by compressed or hot air, is transmitted to the top tup only by means of a piston and connecting rod. The coupling of the two tups is effected by means of an element consisting of steel bands of various length, but of slight thickness, superimposed on each other. Unlike wire ropes, this new coupling element is subjected to no interior and destructive friction when brought over the side pulleys. The steel bands are so carefully adapted to the diameter of the pulleys, both in their thickness and in other respects, that they are never subjected to abnormal stresses.

The steel bands are not firmly attached to the tups, which lie loose on the plates in which the steel bands are attached, while rubber discs are arranged between the tups and plates.

All unevennesses in the load on the steel bands on both sides is practically compensated by the high degree of elasticity of the rubber discs between.

Machine Forging

Work which can be classified as machine forging is of rather a different nature to drop forging. It was originally introduced into the nut and bolt industry, the first machine used for this purpose in 1818 being due to an American inventor. Machines developed for this and similar

purposes are of no great interest to the average engineering student, as they are confined to the mass production of nuts, bolts, rivets, hooks, spanners, shackles, and parts of comparatively rough machines, such as ploughs and ironmongery in general. Many of them come under the general classification of upsetting machines, this being the principal operation done. Stop motion headers, for instance, are primarily used for heading bolts and for all kinds of upset forgings, while continuous motion headers are used for heading rivets, carriage bolts, etc. That is to say, the heated bar is pushed into the machine where a moving die acts as a shear and cuts off the blank. The latter is then gripped against a stationary die, headed, and ejected.

The average class of work which can be economically done on a modern forging machine is shown in Fig. 506, while rather more difficult work, though by no means outside in scope, is shown in Fig. 507, where the pin A of the size shown is made by means of the two dies B and C from 26 in. of 3-in. bar. A good forging machine can produce all sorts of parts of this class on mass production lines, because the pieces are made direct from the bar and the various shapes obtained by upsetting. Hollow pieces formed in a forging machine will show a great saving in raw material over all other systems of production.

The dies of a forging machine are not subjected to heavy and sudden stresses and are not so complicated as those used under drop hammers or in presses. In many cases both sides of the dies can be used, and they can be easily and quickly fitted to or removed from the machine. Consequently a forging machine is also an economical proposition where only a small number of forgings of one pattern have to be handled. The dies are of ample height so that recesses up to four, one above the other,

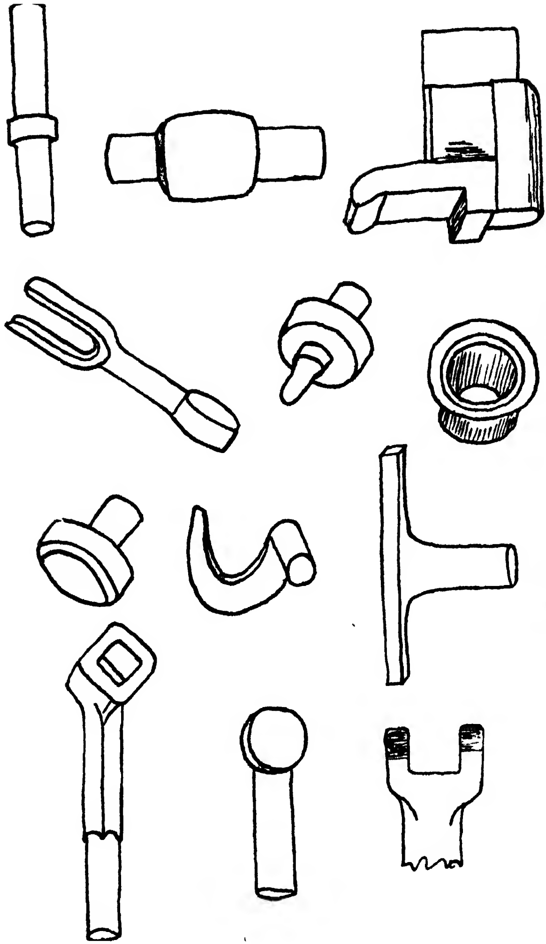


FIG. 506.—Typical Machine Forging Work.

can be sunk. This enables several operations to be performed quickly without losing the initial heat, and furthermore, in common with drop forging, pieces done

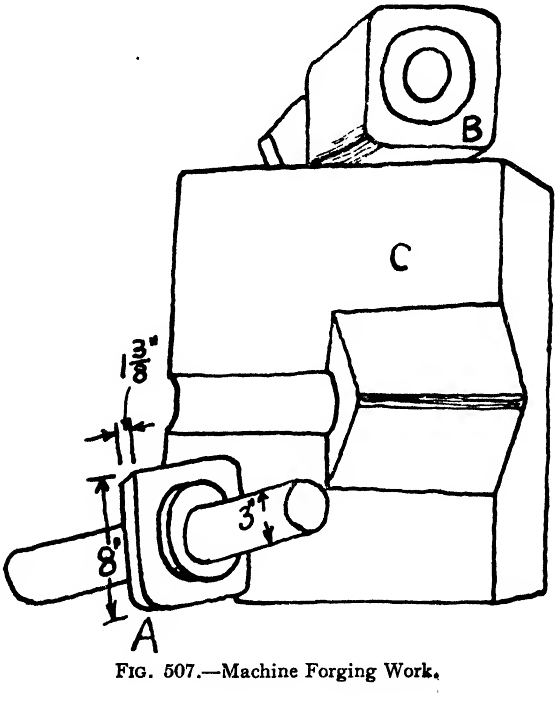


FIG. 507.—Machine Forging Work.

on the forging machine have the correct flow of material which is desirable from the standpoint of strength. In this condition the material is intensified, the tensile strength is increased, while the grain of the material and the flow of the metal will follow closely the contour of

the forging. The diagram in Fig. 508 depicts a typical series of operations in the production of a Y-shaped link

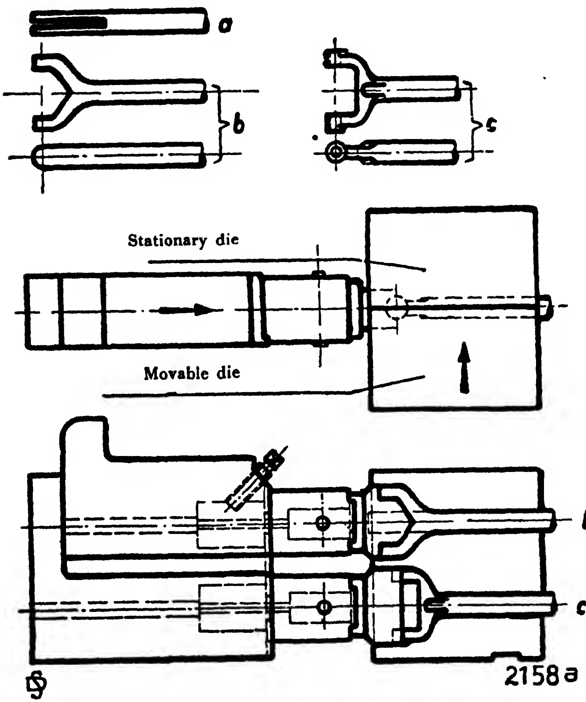


FIG. 508.—Machine Forging of Y-link.

to the form shown in view C. Here the forging for a ball-and-socket joint is made from the slit bar A in two operations, the first of which (B) roughs out the fork to the form shown whilst the second operation finishes it.

Advantages of Machine Forging—Comparison with Drop Forging

In common with all modern machines for manufacturing, forging machines considerably cheapen production, and the saving, as pointed out by the Coventry Machine Tool Co., who are amongst the leading builders in this country, when made in quantities, is so great that many articles previously made from malleable iron or steel castings can now be economically produced in the form of forgings. Tests have shown that the intense pressure has no detrimental effect on the material, but, on the contrary, makes it more homogeneous and better able than before to stand a high stress. Forging machines are as indispensable to a modern smithy dealing with repetition work as drop stamps and hammers, and are largely used to replace or act in conjunction with them. Each of the three types of machines has its special advantages, and most articles made from the bar can be produced more cheaply by the forging machine than by the drop stamp. On the other hand, the latter is more suitable for short pieces of intricate shape.

Forging machines are largely used in railway shops for locomotive and wagon work, and their scope is becoming more and more extended. Wagon brake shafts, side plungers, shackles, brake pull rods, signal joints, wagon door hinges, brake shaft hinges, longitudinal stay ends, rocker bars, and practically all parts with a long shank can be made by them. The great advantage is that a bar of the size of the shank is used and the end upset to the required shape, no swaging being necessary. Any section of material may be used, either round, square, hexagonal, or oblong, as may be required for the shank.

Wagon spring ends, either solid or forked, are now made on these machines by taking a bar of the section of the spring portion and upsetting the ends. This represents a great advantage over the usual method of forming the head of a large billet under the hammer and swaging down the central portion.

Although the majority of the work done is in forging upsets on the end of a bar, forging machines can be used to equal advantage in making hollow forgings. As an example, after the forging has been upset to the outside diameter the bar is punched away without waste, and a bar smaller in diameter than the hole may be used to lessen the fatigue of the operator handling the material.

Costs can be considerably reduced by the forging machine instead of the hammer for assisting drop stamping work when making articles of intricate form on the end of a bar. As a rule, such forgings are made from a billet with a section sufficiently large to allow the end to be drop stamped. After the drop stamping has been completed the remaining portion of the billet is swaged down under the hammer to form the shank. When the forging machine is used to assist the drop stamp a bar of the requisite shank diameter is upset at the end to allow for the drop stamping operation and no swaging is necessary.

It will be seen from a comparison of the two methods that swaging down from the square billet to the round shank is replaced by upsetting the square end from a round bar. In some instances the upsetting time is only one-thirtieth of the swaging time, besides which the forging is much cleaner as the shank is the original rolled bar instead of the irregular shape produced by the hammer. This method can also be used for upsets of large diameter, such as buffer ends, by collecting up the

material in the forging machine and giving the final blow under a heavy press.

The method of operating the machine is very simple. The dies are made in two parts, one half usually being fixed and the other movable. The operator places the end of the bar, which has previously been raised to a forging heat, in the fixed half of the die against a stop, to give the required length of upset, and then depresses the foot lever which starts the machine. The moving portion of the die closes on the material and the stop recedes to allow the advancing heading tool to strike the bar and force the hot malleable end to the required shape in the die. The heading tool then returns, the movable die opens, and the machine remains stationary, with the heading slide and movable die in the backward position. The forging is then removed and, if another operation be necessary, placed in a second recess in the die and the process repeated.

CHAPTER XXIV

WELDING

General Observations.—Welding, as it is understood to-day, is one of the newest engineering sciences and something quite different from the welding operation practised in the blacksmith shop, but, of course, the object is the same—joining two pieces of metal without any mechanical fastening like a rivet or bolt. It involves the action of intense heat to fuse the two sections together with or without the aid of a flux, and the heat may be applied through the medium of the electric arc, gas, or the oxy-acetylene flame.

Each has its own particular sphere of application, but the majority of production work of the class to be outlined presently is done by electric welding. There is considerable difference between production work in the shop in the construction of machine parts—tanks, pipes, base-plates, etc.—and welding done, sometimes in a small way but now quite often by large concerns, in the repair of broken machinery, typical work of the first class being shown in Fig. 509, which depicts a small pressure cylinder with a welded longitudinal seam and the two dished ends welded in, at the instance of Messrs Thompson Bros., of Bilston. The cleanliness of the whole job will be at once apparent. The general procedure in making a gas weld is shown in Fig., 510 when two flat plates are being joined together, or the same procedure could be

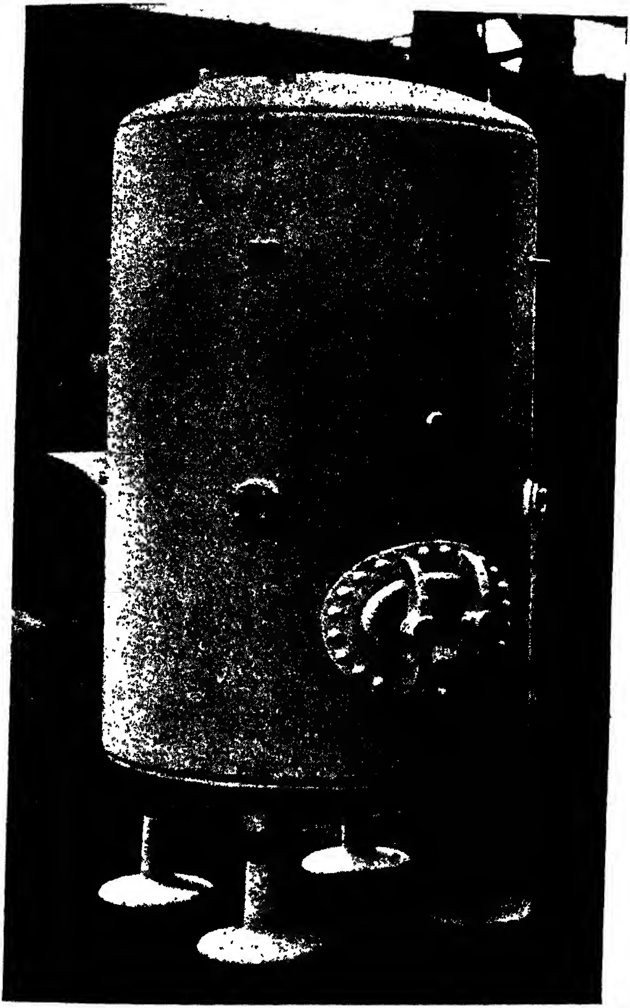
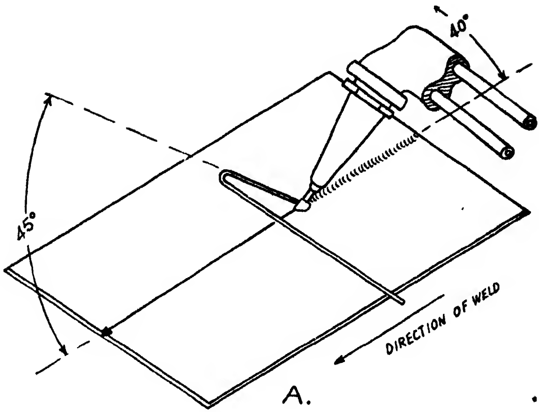


Fig 509.



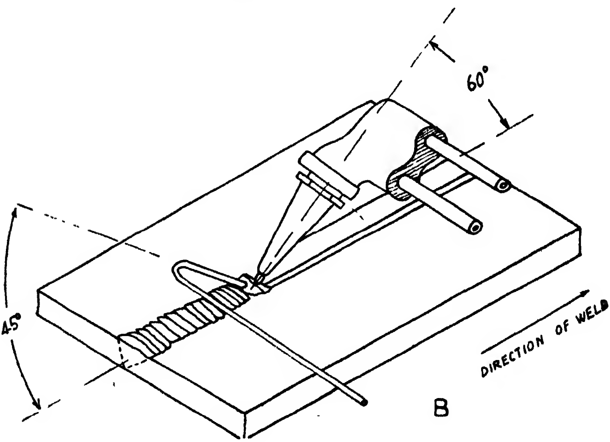


FIG. 510.—Gas Welding.

applied to making the longitudinal joint of a pipe or cylinder. This type of weld is made by playing upon

the adjacent surfaces of a prepared joint the flame of the welding torch. The intense heat heats up the local surfaces to a point at which fusion of the metal begins, the welder assisting the fusing metal from the two sides of the joint to intermingle, at the same time preventing loss through the bottom of the weld if a backing strip is not used. To the puddle of molten metal so formed is added further metal from the welding rod. It depends upon the skill of the welder to so manipulate the flame and welding rod, and what flux is necessary, so that the puddle will be freed of slag, and the vee-shaped space formed by levelling the edges of the plate to be joined is entirely filled with clean metal. In order to prevent undue stress in the metal the parts near the joint should be preheated and the whole allowed to cool slowly. It will also be seen that the welding torch .consists of two tubes uniting. On one end of each of these tubes is provided a hose connection, a control valve, and a grip, and the same general principle is applied in the cutting of metal by the blow torch.

By this means it is possible for one or two skilled men to do a lot of useful work in a general machine shop. Blow-holes in castings, for instance, can be easily filled up, generally without any detriment to the casting, always provided the hole is thoroughly cleaned out and so shaped up so as to remove air pockets and to permit of the proper manipulation of the torch. Cast iron too is comparatively easy to work by this method if the section or sections are first preheated to a black heat, and "cast iron" welding rod is used with any suitable flux sold for the purpose.

In order to avoid burnt metal the end of the rod should be frequently dipped into the flux and continuously fed, except when actually applying the flux.

In the welding of steel the principal point is to prevent

the metal from foaming. This, if allowed to continue, indicates that the flame is localised to too great an extent or that too large a tip is being used. The welding rods used must be in accordance with the carbon content of the steel, and when applied to manganese steel it is important to heat treat it afterwards to restore the original toughness.

Both bronze and copper can also be welded, the former by " manganese bronze " welding rod and the latter by copper, and, in the case of bronze, borax as flux. In this work overheating, as indicated by heavy white fumes, must be avoided, and the flame requires to be held farther away from the metal than in the case of steel. The same remarks apply to nickel, where nickel welding rod and a fairly large tip are required, and here high cooling stresses must be avoided because nickel is brittle at round about 1,000° F. When cold the joint should be mechanically worked to give it the physical characteristics of the rolled metal.

In the case of aluminium, flanged joints and no welding rod are advisable, with the flame adjusted to be slightly carbonising. The surfaces require to be scraped clean and then quickly coated with flux to prevent oxidation, and the weld requires quickly making for the same reason.

In the case of cast aluminium, butt joints for metal up to ¼ in. thick are advisable, and above that a 90° double-bevel joint, whilst a steel or asbestos backing strip is necessary to support the weld metal.

Special Conditions Applicable to Copper

In the welding of any non-ferrous metal particular attention has to be paid to the electrode used and to such

special instructions as are furnished by the makers of proprietory bronzes, monel metal, etc. There is now available too an electrode of the dipped type which has a core of a special phosphor-bronze wire. It has been found particularly suitable for welding the joints of domestic boilers made of copper or any ordinary bronze. It is also very suitable for welding copper or bronze to iron and steel.

In the welding of copper or bronze it is necessary to heat the work before starting the welding operation, slightly for brass and bronze, but to a dull red for copper. Care must be exercised not to pierce the seam being welded by using excessive current and unsuitable manipulation. Copper in general is a comparatively difficult material to deal with, and the production of good work calls for highly skilled and experienced operators, but given this it is quite possible to produce welds on good commercial grades of copper which, if not absolutely perfect, will stand up to service conditions. This is accomplished by carefully hammering each bead of weld metal before it cools, thus breaking up the large crystalline structure of the metal and closing voids caused by gassing. Better results are without doubt attainable by the use of special welding copper. This material, a production of Imperial Chemical Industries, is manufactured by a special process, and a suitable alloy filler rod for use in conjunction with this special welding copper has been produced and can now be supplied in a convenient form.

The proportion of deoxidiser to filler rod is vital to the success of the process, and none but properly coated rods can be expected to give satisfactory results. Care must always be exercised to make sure that the coating is not destroyed by careless handling or bad storage.

It is inadvisable to attempt welding a thick seam without properly bevelling the plate edges, the most satisfactory angle being 60°, except where welding is to be done from both sides, in which case the angle on each side formed by the butting edges should be 90°. It has been found by repeated experiments that the plates draw together during welding at a uniform rate for all thicknesses, and an allowance of $\frac{3}{16}$ in. gap per foot run of weld will be found sufficient for all cases where the plates are free to move. Where possible one plate should be arranged so that it can draw in with the contraction of the weld, but where this is impossible light hammering during welding will relieve the stresses set up.

The appearance of a copper weld should be slightly rippled as in ordinary acetylene welding. If the ridges become pronounced it is a sign that the job was not sufficiently hot, whilst a smooth "cast" appearance denotes excessive heat.

Similar to welds in other metals, copper welds are improved by hammering to "work" the cast structure, and it should be extended to either side of the weld to break up the large grain structure in the parent metal caused by heating. Subsequent annealing, either with the blowpipe or in a furnace, is an advantage.

Basic Principles of Electric Welding

There are two main systems of electric welding—*arc welding*, in which the heat is developed in an arc struck between two electrodes (one of which is usually the work), and *resistance welding*, in which the heat is developed in the contact resistance between the two parts of the work. Arc welding demands skill to ensure that the operator

shall not only produce a joint of sound external appearance but containing metal properly fused into the adjoining material. As a manual process it is applicable to an infinite variety of work, and can be executed in almost any position. Resistance welding is, in general, essentially an automatic process, and is therefore more

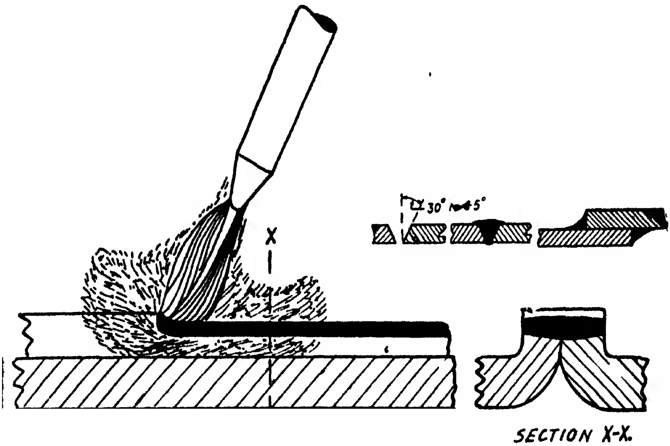


FIG. 511.—Carbon Arc Welding.

applicable to repetition work, on which it can be effected by semi-skilled labour using the special machinery to be described later on. The class of work again can be subdivided into carbon arc welding and metal electrode welding, and the general principle of the carbon arc is shown in Fig. 511. It requires current up to about 400 amps., with an electrode from $\frac{1}{2}$ to $1\frac{1}{2}$ in. diameter according to the current. The arc requires from 35 to

50 volts and is generally fed from a special low-voltage D.C. generator giving about 70 volts; alternating current is not suitable as carbon would be carried from the electrode into the weld and the joint would then contain brittle material. The arc is usually about 1 or $1\frac{1}{2}$ in. long. If too long it encourages oxidation, while too short an arc causes the metal to boil and absorb carbon.

Mild steel plates from $\frac{1}{8}$ to $\frac{3}{16}$ in. thick can be united with a 300-amp. carbon arc at some 3 to 4 in. per minute. This method is in general suitable for rapid work in which the completed weld will not be subjected to a high stress; it is particularly useful for filling holes, building up bosses, and repair work on heavy castings.

Metal electrode welding may be carried out with either D.C. or A.C., a definite projection of metal from the electrode on to the weld taking place with both types of supply. For D.C. the electrode is connected to the positive pole of the supply. Less voltage, current, and power are required than when using a carbon electrode, but the energy (kilowatt-hours) required per pound of metal deposited is greater, though this is only of secondary importance when strength is required.

Arc Welding in General.—Electric arc welding is based upon an exceedingly simple principle. That is to say, if two rods of electric conducting material be connected to a suitable source of potential difference, and be then placed in contact, the low electric resistance of the contact permits heavy current to pass; intense heat is produced, and this is sufficient to vaporise the conductors at the point of contact. On separating them slightly the current continues to flow through the vaporised material and an "arc" is produced, one or both of the electrodes being continually consumed to maintain the conducting vapour path. A welding arc

may be produced with either D.C. or A.C., and with carbon or metal electrodes, but a minimum potential difference must be available at the electrodes before the arc can be struck; with carbon electrodes this is about 40 volts for D.C. and about 30 volts for A.C., but greater values are required to maintain stable arcs. For a given current the voltage required between metal electrodes is appreciably less than between carbon electrodes.

Should the current increase from any cause, more material is vaporised, the cross-section of the conducting path increases; its resistance, therefore, decreases, and a lower potential difference is required. If the applied potential difference be constant there will be a surplus voltage which will cause the current to increase still further. Similarly, any decrease in current would produce a still further decrease.

The essentials of a good weld in the general run of engineering work are that the surfaces to be united be thoroughly fused and intimately mixed with the added metal, while the slag and oxide must be eliminated. The filling metal must be deposited in a molten condition *after* the surfaces have been melted.

Lap joints, butt joints, and combinations thereof are commonly used for joining plates. The edges of a butt joint must first be bevelled, and then melted from the bottom of the vee upwards, filling metal being run on to the bottom and sides of the vee, and built up to slightly above the level of the plates. The construction of various forms of plate joint is indicated in Fig. 512, where the added metal is shown black.

The filling metal must always be of a composition adapted to that of the metal to be united, for the weak point in a weld is the boundary between the original and the added metal. In many cases the formation of a hard

brittle zone, due to too rapid cooling, can be avoided by preheating the work. The parts should be cleaned by mechanical means prior to welding, and where a joint must be welded in several layers the flux should be chipped off each layer before the next layer is commenced.

Arc welding is extensively employed for the joining and repairing of cast iron, wrought iron, and steel parts, for repairing castings, joining pipes, building tanks and barrels, connecting the members of steel structures, building up worn parts, such as rails, shafts, and the different classes of work to be shown presently.

The welding of a long seam should not be started at one end and continued always in the same direction or unequal expansion and contraction will result in distortion and severe stresses. The joint should be tack-welded in a few places and completed in sections, starting at the centre then doing a section on one side some distance away, then a similarly placed section on the other side, and so on.

General Procedure in Arc Welding

Joints.—As the reader will now have inferred, the principal purpose of arc welding is the making of joints between steel plates, and these welds take the form of flat butt welds, corner welds, tee-welds, lap welds, and fillet welds, and twenty-two different forms are shown in Fig. 512 with typical procedure in making them (reproduced by the courtesy of Messrs Metropolitan Vickers Ltd.). They apply in particular to welding as done with a series of electrodes supplied by this concern, but they give a

very good general idea of modern welding as made use of in the manufacture of the various equipment illustrated elsewhere. But apart from skill in welding, which can

FLAT BUTT WELDS

SYMBOL	EXAMPLE	WELD	PARTICULARS	
A		LIGHT	L·2T D·T/2	FOR 1/8" PLATES
B		HEAVY	S·T/2	
C		LIGHT	L·1·5T D·T/4	FOR 3/16", 1/4" & 5/16" PLATES
D		HEAVY	S·T/2	
E		LIGHT	L·T	FOR 3/8", 7/16" & 1/2" PLATES
F		HEAVY	L·1·5T D·T/4	
G		LIGHT	L·1·5T	FOR 9/16" PLATE AND OVER
H		HEAVY	L·T D·T/8	

WELDS "L" F and "C" TO BE SEALED AT BACK

CORNER WELDS

SYMBOL	EXAMPLE	WELD	PARTICULARS
L		LIGHT	L·1·4T
LR		FULL STRENGTH	L·T
M		LIGHT	O·3T
MR		FULL STRENGTH	L·T O·3T
W		LIGHT	O·DIFFERENCE IN PLATE THICKNESS
WR		FULL STRENGTH	L·T O·DIFFERENCE IN PLATE THICKNESS

"W" and "WR" ARE FOR UNEQUAL PLATE THICKNESS

TEE WELDS

J		LIGHT	L·T/2 3/16" MIN SINGLE OR DOUBLE WELD TO BE SPECIFIED
K		HEAVY	L·1·2T OR USE DOUBLE "J"
N		FULL STRENGTH	L·1·2T DOUBLE WELD
N		FULL STRENGTH	L·1·15T C·T FOR 3/8" TO 5/8" PLATE WHEN DOUBLE WELD CANNOT BE USED
P		FULL STRENGTH	L·6T C·5T FOR PLATE ABOVE 5/8" WHEN WELD "K" CANNOT BE USED

LAP AND FILLET WELDS

R		LIGHT	L·T O·NOT LESS THAN "T"
S		HEAVY	L·1·4T O·NOT LESS THAN "T"
T		LIGHT	L·T/2 3/16" MIN
U		HEAVY	L·1·4T

FIG. 512.

only be acquired by practical experience, success depends to a large extent upon the operator manipulating the electrode in strict accordance with the makers' instructions furnished with it, because not only is one type better

suited to a particular run of work than another, but different voltages and different currents are specified.

Apart from that it will be readily apparent that the preparation of the plate edges is a very important factor in ensuring successful work, and in shops doing a large amount of this class of work special machines are installed for doing this.

In riveted structures accuracy and exactness of edges is not of great importance because the plates are drilled and joined by rivets on lines independent of the edges. A good riveted structure shows the exactness of its manufacture by the accuracy of the rivet centre lines and the rivet holes. With welded structures accuracy depends upon the exactness of the bevelled edges, which are joined by the welding material.

Fig. 513 shows the more usual methods of forming plates for welded joints, and economy calls for accurate formation of the edges as deviation of only a few millimetres will increase the amount of welding material by 20 to 50 or more per cent. Furthermore, in addition to the cost of electrodes and electric current and labour, if the preparation is not accurate there is difficulty caused by the larger amount of shrinkage stress, the avoidance of which will save a lot of trouble and waste of time. Accuracy of preparation means a saving in initial cost and time and ensures the best possible results.

Atomic Hydrogen Welding

This is quite a recent development in the welding field, and it would appear to be one which has considerable possibilities. In this process a single-phase, alternating-current arc is maintained between adjustable tungsten

electrodes and hydrogen gas is fed to the arc around the electrodes. The hydrogen molecules are broken up into atoms by the intense heat and, with their recombination

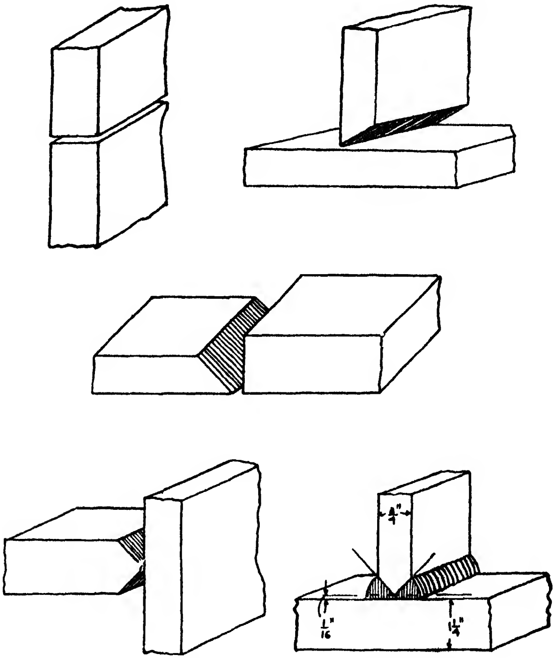


FIG. 513.—Preparation of Plates for Welding.

outside the arc, heat is liberated far in excess of that obtainable by any gas flame alone. This heat is used to fuse the metals to be joined and results in high welding speeds. Where additional metal is required a filler rod may be fused into the work.

Hydrogen, being an active reducing agent, prevents the formation of oxides and hence produces a uniformly strong, ductile, and smooth weld. The metal being welded is not in the electric circuit and need not be grounded or insulated. The atomic flame, constantly maintained but broadly adjustable in size and intensity, lends itself to a wide range of work. Insulating transformers furnish the required constant voltage for the welding and control circuits. The arc is struck at 300 volts, but while welding the arc voltage and current are varied according to the class of work being welded.

The action is somewhat peculiar, but the special property of the process is the intense localised heat available, well over 3,000° C. So that this atomic hydrogen flame possesses all the necessary properties for high-speed welding, and, due to the steep temperature gradient and catalytic action of the metal in the welds, the speed of recombination is high, so that one obtains a very hot concentrated flame. The recombination of the hydrogen atoms at the surface of the liquid metal in the weld replaces to a certain extent the oxidation reaction always present when welding is done in air. This reaction tends to keep the surface of the metal molten for a longer period and tends to permit any occluded gases to escape. This is important, due to the fact that, although molten iron will not absorb much hydrogen gas, it will, when overheated, absorb fifteen times its own volume of gas at normal temperature and pressure. Therefore, due to this delayed cooling of the surface, the occluded gases have time to escape before the weld metal solidifies. The principle is based upon a somewhat involved theory, but briefly, when an arc is struck between two tungsten electrodes and a stream of hydrogen gas is blown through the arc core, the high temperature of the arc completely

dissociates the whole mass of gas in contact with it. This atomic hydrogen diffuses rapidly from the arc core to the cooler regions, where it recombines into the molecular state. In so doing the hydrogen gives up the energy which has previously been absorbed from the arc. Thus there results an extremely hot flame of a single gas without combining with oxygen as is usual in all other welding flames. Outside this zone the molecular hydrogen burns in the usual way.

Welding Procedure

According to Messrs Metropolitan Vickers, who have developed this process as originally discovered in the works of the American General Electric Co., the operator, by his control of the torch, which is, of course, connected to a supply of hydrogen gas, permits a slight stream of it to flow through the arc, which may be struck either by allowing the electrodes to touch and then separate or by drawing the separated electrodes over a carbon block. As soon as the arc strikes, a very intense arc flame extends fan-wise from the tungsten electrodes to a distance of 1 to 2 cm., according to the distance between the tungsten electrodes. This fan when brought in contact with the parts to be welded melts the metal, giving a bright surface which readily unites with the abutting edges.

The arc flame should be oscillated slowly over the job in the case of a wide weld, but this is not necessary when joining light gauge materials.

Due to the reducing action of both atomic and molecular hydrogen the molten metal under the flame is particularly clean and bright. Further protection of the weld metal is obtained from the burning molecular hydrogen which completely surrounds the electrodes. In this connection

it must be pointed out that mild steel has the property of absorbing hydrogen, which may readily form blow-holes in the weld, and it is necessary to point the arc flame over the weld so as to allow the metal to cool more slowly. This gives the gas time to come out of the weld metal, leaving it free from porosity.

In welding practically all materials filler metal is necessary. This can be applied in the form of rods manipulated in the left hand as in gas welding. Sometimes it is more convenient to place strips of the metal in the joint to be welded. This is the usual procedure in automatic welding, whilst in the case of butt joints the filler metal is slightly larger than the section to be filled so as to allow for irregularities of the joint and a slight reinforcing of the seams in line with the usual welding practice.

Fig. 514 illustrates typical practice. So far as flat butt welds are concerned, these may be made on all plates up to ½ in. thick without any special preparation, but they are preferably welded from both sides. In doing this there is a possibility that the welds will not meet in the centre, and this, obviously, is dangerous and may cause trouble. To get over this the usual type of single and double vee preparations are employed. The single vee preparation may be entirely welded from one side, although for any pressure work it is always desirable to put a run on the inside.

Method (*a*) should be used with filler metal when a full strength weld is required or when a radius is required between the plates. In the case of light welds no metal need be added, the edges merely being fused together. The second type is used when the sections are of unequal thickness, or for ease of assembly of the parts. One member rests on the other, thus affording greater rigidity

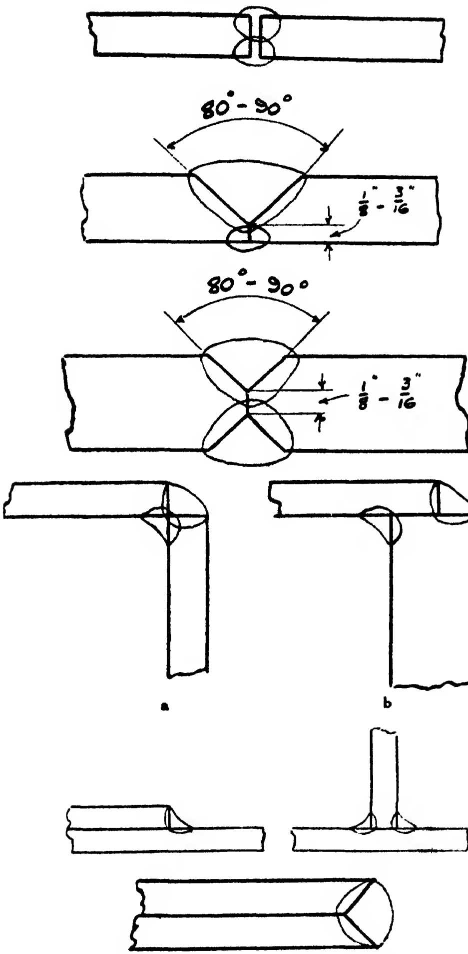


FIG. 514.—Atomic Hydrogen Welding.

to the unit. Fillet welds may be put in the inside as desired. This type of weld is suitable for all plate thicknesses. Fillet and tee welds follow the usual practice for arc welding.

The edge type of weld is very useful, and in the thicker plates it is the practice to form a shallow vee, which is filled convex with filler metal. This is very essential so as to ensure the necessary thickness of weld metal.

Advantages of the System

In this process there is a screen of hydrogen which completely shields the weld metal from atmospheric contamination. In fact, the atomic hydrogen is an even more powerful reducing agent than the molecular form. This means that oxides and nitrides are kept down to a minimum. Not only is this so, but a proportion of the carbon in the metal also disappears. When welding low carbon steel, owing to the fact that the only thing which varies in the composition is the amount of carbon, apart from the small addition of tungsten, it is convenient to use a filler wire with double the amount of carbon High carbon steels may also be welded with this process, using a filler metal with between 20 and 30 per cent. more carbon than the base metal, as the loss of carbon is less than with mild steel, while alloy steels do not seem to change at all under the flame. Thus it is possible to weld nickel chromium steel alloys even if they contain appreciable carbon with filler metal of the same composition. Thus the process may be used for repairing and building up worn parts of press tools and various other parts made of tool steels. When welding these high carbon steels it is necessary to preheat the parts to 400° C. before

welding, except in the case of very small parts with few changes of section. As soon as the necessary temperature is obtained the atomic flame is applied to the job and welding proceeded with as in the case of oxy-acetylene. The parts should be allowed to cool slowly, and after the necessary grinding may be hardened in the usual way. The deposited metal will be homogeneous and free from porosity.

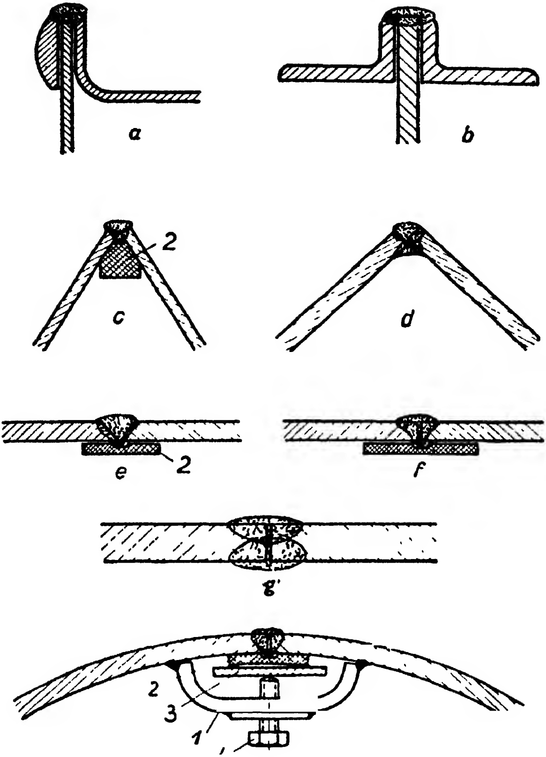
The protection which the process provides makes it very suitable for the welding of stainless steels of all kinds. The welding procedure is the same as for mild steel, and filler metal is commonly used in the form of wire of the same composition as the base metal. If the steels are of the 18/8 variety it will be necessary to heat treat the welded parts in order to retain their stainless properties. With the newer types, which contain elements to delay the carbon precipitation which gives the harmful effects, it is not necessary to heat treat as under normal welding conditions no part of the weld or base metal is at the critical temperature long enough to harm the material. The actual welding operation is extremely simple, with the result that particularly smooth-flowing welds are made. The type of joints required are very much after the style used for mild steel. Due to the increased coefficients of expansion of these materials greater allowances have to be made to allow for this, and welds should be allowed to contract freely so as to prevent stresses being set up in the welds wherever possible.

In making butt welds on thick plates there is a tendency for the extreme edges of the plates to lift. This may be counteracted by raising the joint slightly and allowing it to pull straight.

Automatic Arc Welding

Typical work of the carbon arc welding process is shown in Fig. 515. The electric arc as struck between a carbon electrode and the work plays a subordinate part compared with the metal arc in the case of manual welding. This is largely attributable to the fact that a seam welded by way of carbon arcs is very brittle unless special precautions are taken, but if the welding process is rendered automatic there is a possibility of overcoming this defect. To this end it is essential to deprive the air of the oxygen surrounding the carbon by a burning process and to make provision that the flame also shrouds the melt. From a practical aspect this can be realised by leading past the immediate vicinity of the arc a special paper strand, which thereupon burns and shrouds the arc by its flame. The carbon is always maintained at a suitable distance from the work by being adjusted automatically according to the loss by burning.

The fulfilment of these conditions has rendered possible the production of welded seams possessing good mechanical properties and flexibility. The carbon arc can therefore be adopted for automatic welding plant. Two outstanding advantages of the carbon arc are: (*a*) the much greater welding speeds obtainable, and (*b*) the smaller degree of distortion. In consideration of the latter factor clamping devices, which are not only complicated but also retard the working process, can usually be discarded. With the carbon arc the uniting of parts to be welded is chiefly effected by fusing the edges to be joined. Consequently edge welds play an important part in the present case. To increase the depth of fusion with thick sheeting and special jobs a filling wire is used which is fed through a nozzle to the core of the arc whilst the work that has



a — Edge weld,
b — Edge weld,
c — Edge weld with filling wire, single sided,
d — Edge weld with filling wire, double sided,
e — Butt weld with filling wire, single sided,
f — Butt weld without filling wire, single sided,
g — Butt weld without filling wire, double sided,
h — Butt weld, copper strip placed in position,
1 — Clamp,
2 — Copper strip,
3 — Faceplate,
4 — Clamping screw.

FIG. 515.—Carbon Arc Welding. A.E.G. System.

free access to the arc is thoroughly melted. Therefore that part of the arc whose heat is otherwise lost by radiation is utilised for fusing in the filling wire.

Metallic Arc Welding

Principles and Practice of the Metallic Arc.—As opposed to the carbon arc which makes use of a carbon electrode there is the metallic arc system of welding in which a metal rod or wire is substituted, so that the electrode as well as the work fuses and serves as a filler, the electrode being of a soft grade of iron, low carbon steel, or other material according to the nature of the work being done. The wire used is quite thin, usually round about $\frac{1}{8}$ in. diameter. The heat generated by the arc melts the end of the electrode and, in addition, fuses the surface of the work being welded over a small area. Thus the two metals being fused, and at the same time coming into ultimate contact, they are completely intermixed, and further, as the supply of heat to the arc is constant, the deposition of metal from the electrode is uniformly continuous.

Essentials of a Good Weld

Electrodes.—It should be said at once that while anyone can weld, ability to do really good work is only acquired by experience, except, of course, in that class of electric welding to be dealt with presently, which is done on automatic machines. In addition, the use of proper electrodes of proved quality is most essential, because a successful weld, no matter what its nature, depends upon the application of proved metallurgical and scientific principles. As pointed out by the Quasi-Arc

Co., who have wide experience in heavy welding, the main essentials of good welding are for the heat put into the work during welding to be so limited that it will not overheat and produce brittleness in the metal of the work. The mill scale, etc., on the surface of the work must be cleaned away efficiently by an acid slag so that perfect diffusion will be obtained between the weld metal and the metal of the work. The weld metal and steel of the work must be protected by a reducing flux from contact with atmospheric gases, as otherwise defects will form and the welded joint will be brittle, unreliable, and subject to corrosion. The weld metal should be deposited under such conditions as to render its structure absolutely uniform and of a fine crystal grain, whereby a reliable joint of a high value of mechanical strength will be produced.

These conditions will only be attained by the use of electrodes suited to the work, and which are coated with a robust mineral flux having those physical and chemical properties whereby a weld of the highest mechanical strength and purity is obtained. This flux melts in a continuous flow from the electrode to the work, enclosing the arc and, by reason of its special composition, protecting the weld metal during deposition from attack by the atmospheric gases, thus enabling a pure and homogeneous metal to be deposited; it also protects the metal during cooling, so that a certain degree of annealing takes place. When cold the slag easily separates from the metal. The flux being acid in character thoroughly cleans and removes all mill scale and dirt from the work. The electrode requires only a small current for fusion by reason of the low melting-point of the flux, while its spiral application to the steel core ensures that the slag flows automatically over the metal.

In many processes of welding the work is overheated and rendered brittle by reason of the large amount of heat required for the operation, but owing to the small amount of heat required for fusion this objection is absent when these electrodes are used, and consequently very little thermal disturbance occurs in the work.

All this makes for what should be a sound mechanical joint, and it is used in repair work both in cast iron and malleable; it can be used for filling up worn parts of machines. The current consumption is low compared with that of the carbon arc, rarely exceeding 175 amps., and being as low as 10 amps. for thin work; but appreciably more skill is required in the manipulation of the metallic arc than with the carbon arc. The proper size of electrode must be co-ordinated with correct current, and to obtain work of a uniform quality it is most important that the correct adjustment of the arc be maintained, and in hand work this calls for a steady hand; and this again requires a properly designed holder, one which does not become uncomfortably hot in service, and if the work is of a nature where this cannot be avoided, a water receptacle should be maintained near by for cooling purposes, or the operator should have two holders available for alternate use. Then both the direction and position in welding are factors which influence the quality of the finished work, and an experienced operator should be able to weld in any direction, as this is determined by the arrangement of the work, the liability of grounding the electrode or holder, deposition sequence, the type of electrodes used, and the practical necessity of keeping the hand over a cool portion of the work. Backward welding is used with bare and coated electrodes, but in the latter case it is necessary to weld downwards in order to prevent slag inclusions in the weld. When carbon electrodes are

used, forward welding without a welding rod is employed for leaf, flanged, and angle-butt joints, but when a welding rod is necessary backward welding is almost exclusively used; and again, with carbon electrodes, a weld can be made in any position or direction if the joint edges are merely fused together without the use of a welding rod.

So far as the human element is concerned in making a good weld, there is first of all the necessity for judging the best angle for the electrode, which for carbon electrodes or flat work is usually about 75°. This permits of a steady, unbroken stream of heated air and gases which, stabilising the arc, permit of better control and effective manipulation. Once the metal arc is struck it should only be broken when necessary to change the electrode or the position thereof in the holder, because a continuous arc stream is essential for the obtaining of sound deposited metal. Striking and breaking the arc is an art to be acquired in this class of work. If the electrode is not withdrawn quickly enough after it is applied to the work to make contact to form the arc it sticks to the job and "freezes"; on the other hand, in an effort to prevent this the beginner increases the length of the arc beyond that which the equipment can sustain, and this results in the arc being ruptured. The correct procedure for striking the arc is really similar to that of striking a match, the purpose being to make contact with the electrode on the work and then to instantly raise it laterally to a correct arc length. The inertia of the hand and the electrode holder overcomes the tendency to stick, and the motion being in the same plane as the work, there is less liability of exceeding the maximum arc length. The same motion is used to break the arc so as to prevent the formation of that deep, spongy, oxidised crater in the deposited metal which is

formed when the arc is broken by pulling away the electrode at right angles to the work. This is the main cause of porous welds. The arc, where possible, should always be broken on the base metal and not on that deposited, and further, before doing so it should be shortened to the minimum, then, with a quick side break, the crater can be kept quite small.

After the arc is struck it has to be maintained, and whilst this is relatively easy with a carbon arc because of its greater length, wider arc range, and the slow rate at which the electrode is consumed, the metal arc is difficult to maintain in comparison because the electrode is rapidly consumed. This results in the arc being lengthened unless the electrode is fed towards the work at a uniform rate, and it is more difficult still to maintain with alternating current than it is with direct current on account of the periodic reversal of the direction of current flow.

In using a metal arc one holds it as short as possible, because when it is too long highly oxidised metal is deposited. Further, a long arc will increase the amount of oxide in the immediate vicinity of the deposit, which, on being fused into the latter by being welded over, tends to produce poor metal. It is between these two extremes that the correct welding arc lies. An 18-volt arc is about $\frac{3}{32}$ in. long, though an arc as short as 8 volts can be held by an expert operator using $\frac{1}{16}$ in. bare electrode on $\frac{1}{8}$ in. plate.

Faults.—The depth of crater is one of the vital points in a good weld. The height of its edge above the base or deposited metal should be equal to the penetration of the electrode material below. Small penetration results from either too low a current or too long an arc, or it may be due to the melting-point of the electrode being lower than that of the base metal. Too high a

current will cause excessive penetration, though where necessary increased penetration can be secured with suitably coated electrodes, particularly those of coated nickel steel.

Then the matter of oxide inclusion is important too; the smaller it is the better should be the metal deposited, and good electrodes and a short arc are essential to maintain this condition. At the same time a low-current density, together with a short arc, is also conducive to small oxide deposit, and that has therefore to be duly taken into consideration.

In the matter of slag flotation, which results from a large percentage of the chemical constituents of the electrode being lost on fusion, the slag floats to the top of the deposit when it is in the liquid state, forming a layer of uniform thickness over the entire deposit. If this is made on base metal of high thermal conductivity and with a relatively low amperage for the size of the electrode used, the deposit is rapidly chilled and thus tends to entrap slag. Some of the elements which go to make up the slag are incorporated in the electrode to act as a flux or cleanser. Manganese, for instance, and the slag so formed performs a useful function in keeping the air away from the molten metal and so keeping down its tendency to oxidise. But the slag itself must be kept in a state of flotation, and this calls for a lateral motion of the electrode, if it is of the coated variety, so as to keep the metal hot; and once the arc has been broken and the slag coated the latter must be chipped and cleaned off from the previous deposit at the point it is desired to fuse. On account of the difficulty of getting the slag entirely out of the crater formed when the arc is broken the deposit should be started some ½ in. back from the end of the previous deposit in order to melt the slag in the

crater and permit it to float out. To minimise the liability of slag inclusion from this source the arc, whenever possible, should be broken where the formation of a crater is of no detriment.

In the case of carbon electrodes the slag is due, in the main, to the elimination of vaporised carbon deposited in the weld. When filling up blow-holes in castings the molten foundry sand, unless thoroughly chipped out, will form a heavy slag, but if the electrode is carefully manipulated the slag can be kept molten and floated to the surface of the metal. It must then be removed by means of a chisel-faced hammer or pneumatic roughing tool, taking care always to use the least possible force in doing so, and when more than one layer is used it must always be removed from each one prior to the next being deposited.

Another cause of bad welding is porosity in the deposited metal. This is principally due to a dirty welding surface, but it may be caused by entrapped air, gas in the base metal, gas in the electrode, or too high a current. Both cast iron and non-ferrous metals are liable to be troublesome on this account, and in the case of cast iron this condition results from the formation of CO gas from the free carbon in the metal if the percentage thereof is high. The remedy is to prevent as far as possible the release of gas by either using an alternate section sequence or periodically stopping the welding. Porous metal is usually the cause of incipient cracks, which spread when the part is subject to its normal working stresses.

Typical Applications

Repairs.—Whilst the principal importance of welding, as will now be apparent, lies in its use for fabricating

machine and structural parts—boilers, shells, containers, pipes, etc.—it has been successfully applied over a number of years to repairing broken and fractured machine parts. A broken casting may happen to any machine; the replacement of the casting may prove a very costly matter, and without welding such repairs are in the majority of cases

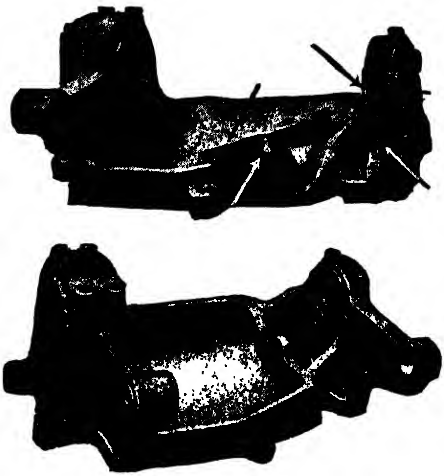


FIG. 516.—Repair to Lathe Bed.

impossible to effect. A comparatively simple case, but amply illustrating this point, is shown in Fig. 516 by the courtesy of Messrs Barimar, where the fractured lathe bed has been successfully repaired equal to new at a fraction of the cost of a new one. Where welders are employed in the workshop, a job of this class can usually be undertaken on the site, but it must be borne in mind that this branch of the business is highly specialised,

and it may be a great deal more intricate than what is shown, which is a straightforward job in cast iron. The majority of the metals can now be welded, but specific instructions for doing so are issued by firms in the metal trade, and by reason of the rapid advances in the science they should always be consulted; and here again such jobs as the motor-cycle crankcase, shown in Fig. 517,

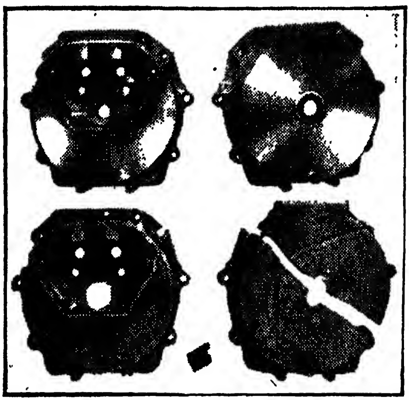


FIG. 517.—Crankcase Repair.

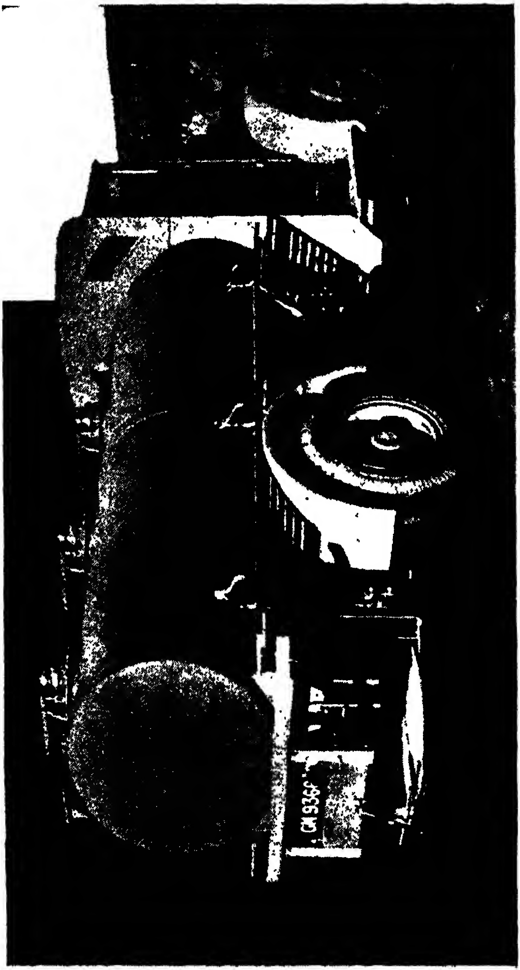
whilst appearing simple, are something in the nature of mechanical "surgery," which calls for considerable skill and quite frequently special equipment. In Fig. 518 is depicted another seemingly simple job, that of repairing a small crankshaft. Here considerable accuracy is called for, because the correct width of the journal has to be maintained. Here is depicted the operator, wearing thick gloves, with his face-shield in one hand, and in the other the positive cable, connected to an insulated

holder into which the feeder rod is clamped. The rod, which, of course, acts as the positive electrode, is of 5 per cent. nickel steel for this job, and is coated with an anti-oxidising flux containing an asbestos compound and different chemicals. The job itself forms the negative electrode, the current passing out to the negative lead *via* the table.

FIG. 518.—Welder at Work.

Typical Production Work

Tanks and Cylinders.—Perhaps the most commonly seen example of everyday welding in commercial steel is the petrol carrier and the petrol storage tanks installed below the common petrol pump, and Fig. 519, at the instance of Messrs Thompson Bros., of Bilston, shows a typical example of the class of



519.—Wel Petrol

work. Here strength with lightness is an important consideration. These road vehicles carry tanks of a capacity up to 2,500 gals. for petrol, and even 3,000 gals. for lubricating and fuel oils and other liquids, and a full petrol load may weigh 9 to 10 tons, so it is easy to realise that the tank structure has to be extremely strong. The problem of mounting the tank on the chassis securely without fear of undue stresses being set up by the flexing of the chassis when traversing rough ground has also to be considered.

A feature of these tanks is that they are made with longitudinal seams instead of the plates of metal being joined together around their girth. This form of construction gives strength in the direction in which it is needed.

For petrol, oils, etc., mild-steel plate, usually $\frac{1}{8}$ or $\frac{3}{16}$ in. thick, is generally employed. For milk, beer, etc., Staybrite stainless steel (which resists the acids in such liquids) is used, but this is a much harder metal to work. In some cases $\frac{3}{16}$-in. aluminium sheet is employed.

Very often it is required to keep the contents cool or warm, and for this reason Alfol (metal foil) or cork lagging is used, the outer panelling being afterwards affixed to the wood framework which, in such instances, is employed.

Tanks may be as long as 22 ft., and the metal plates of the full length and about 6 ft. wide are cold rolled between two lower fixed rollers and one upper adjustable roller. Any radius down to 6 in. can be obtained. If thicker metal, say $\frac{1}{2}$ to $\frac{3}{4}$ in., has to be rolled, it is first brought to a black heat.

The end bulkheads are domed and flanged in an hydraulic press. When the tank cylinder is completed, interior baffles to prevent surging, or partitions to divide

the tank, are fitted in position, and thereafter the domed ends are pressed in, their 1-in. flanges being welded to the barrel on the inside as well as on the outside. The freshly welded seams are exceedingly smooth, but, of course, have to be finished off by a portable high-speed grindstone if the joints are not to be concealed by lagging. The tank is then pressure tested.

In fixing various fittings and mountings to the tank, welding is again almost exclusively used.

Welding Stainless Steels

A further development is the stainless-steel milk tank for carrier wagons. Steels of the stainless variety have developed considerably during the past few years, and whereas some years ago the 12 per cent. chromium steel was mainly used, to-day the 18 per cent. chromium 8 per cent. nickel steel is the principal type used for all tanks, chemical plant, etc.

This latter type of stainless steel is now marketed by several manufacturers under various trade names, such as Staybrite, Anka, Maxilvry, etc. They are of the austenitic type, and contain nickel-chromium carbides in solid solution.

Until recently this type of steel was susceptible to "weld decay," that is, the steel, when heated to about 700° C., suffers from loss of resistance to corrosion, so that a weak zone occurs near the weld. This was caused by precipitation and segregation of the carbides at the grain boundaries and could only be cured by a subsequent heat treatment after welding.

Now, however, these steels have been improved by the addition of suitable alloys which prevent this "weld

decay," and heat treatment after welding is now unnecessary.

The Quasi-Arc Co., among several important developments in the welding field, produced some years ago a stainless-steel electrode, which is not only easily applied but also deposits a metal that is of the 18 per cent. chromium 8 per cent. nickel composition, capable of making a perfect junction with the steel. The electrode incorporates a special flux which prevents any defects, such as oxide, etc., from entering the weld metal, so that the weld is clean and has a resistance to corrosion equal to that of the parent steel. Further, special alloys have been added to the electrode which prevent "weld decay" from occurring in the weld metal. With this electrode thoroughly reliable welds can be obtained with most commercial types of stainless steels, and especially those of the nickel-chrome variety.

These electrodes can also be usefully employed for reinforcing other steels with a layer of stainless steel. By this means a stainless-steel layer can be obtained of about $\frac{1}{16}$ in. or thicker, as required. Typical instances of such applications are the reinforcement of pump spindles, pelton wheel buckets, valves, etc., as used in hydro-electric installations. By the addition of this surface layer the life of such parts under corrosive action is greatly increased, so that the plant can be operated over a greater period and its efficiency maintained.

The stainless-steel electrode can be used for welding stainless steel to mild steel, as in the case of high-pressure steam valves, etc., but where a stainless weld metal is not required, the uranium electrode may be used for this purpose, as in the case of welding mild-steel waterjackets to stainless steel vessels.

Corrosion

In this connection, and the remarks obviously apply also to the majority of structural welding, gas holders, pipes, tanks, etc., the effect of corrosion on the welded joint is of considerable importance. This matter has been the subject of much laboratory research and is naturally one which concerns those engaged in the particular class of work, such as joints in bridges and tanks exposed to dampness, welds in stems, stern posts, and shell-plating of ships, liquor tanks in gas works, boilers, pipe-lines, and in numerous other cases where corrosion is active. Rapid corrosion of the weld entails a short life and may lead to considerable loss and even dangerous results.

The Quasi-Arc Co. have given considerable attention to the elimination of all corrosive agents in designing their electrodes, in order to ensure that the weld will be homogeneous and free from oxide and other defects.

Manganese Steel

Manganese steel is always a material more or less difficult to handle, and whilst welding facilitates work done in this metal, it also calls for special consideration. Manganese steel is principally used for machine parts which have to resist abrasion, such as stone-crusher jaws and dredger buckets, and it has been in extensive use for many years in rail crossing and junction work. In this, as Fig. 520 will show, intricate work of the class is greatly facilitated by welding, always provided that the electrode deposits a weld metal giving resistance to wear and abrasion equal to that of the manganese steel, and, in addition, strength and toughness.

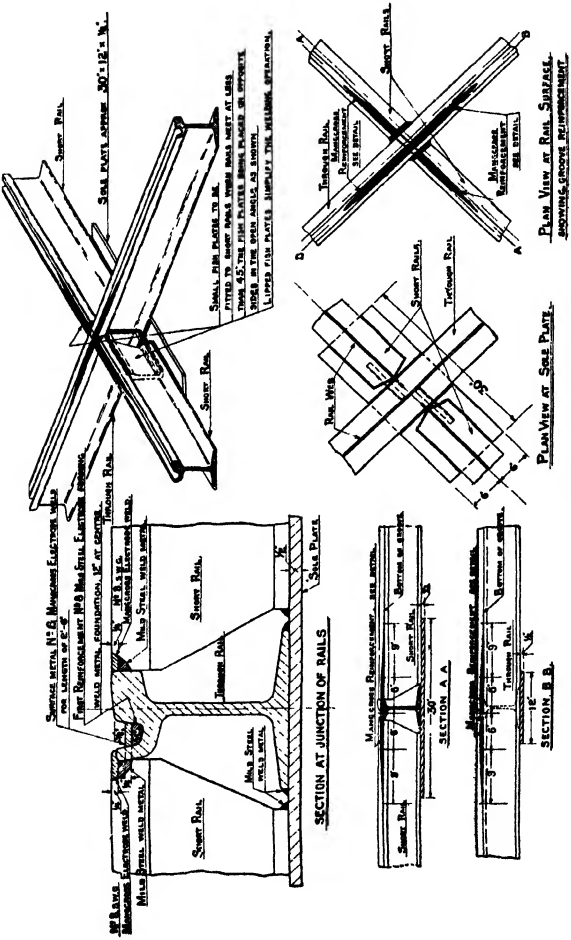


FIG. 520.—Welding Rail Crossings.

The metal deposited when using the Quasi-Arc Co.'s "Mangcross" electrode is an austenitic steel, tough and comparatively soft, but it rapidly "work hardens" when subjected to load or hammering. It is also possible to make strength welds on manganese steel as the Mangcross weld metal is tough and has no tendency to hot crack when deposited in the proper manner.

Mangcross electrodes are applied in a similar manner to Quasi-Arc mild-steel electrodes, except that they should be held nearly vertical and the runs of weld metal kept fairly narrow. By their use it is possible to fabricate constructions which will have the wearing properties of manganese steel by using either mild steel or carbon steel as a foundation.

In reinforcing manganese steel it is important to avoid undue thermal disturbance of the work, and therefore the first layer should be made with a small gauge electrode (No. 10 or 8) before adding subsequent layers of metal with No. 6 electrodes. During welding the work should be maintained at a low and even temperature. The use of excessive current must be avoided.

Laboratory tests on manganese steel bars, butt welded with Mangcross electrodes, have given an average tensile strength of 30 tons per sq. in. Similar bars tested under alternating impact and bending stresses have given an average of 7,500 alternations to fracture the weld, as compared with 600 alternations to fracture a similar weld made with manganese steel. These high results are due to the finer crystal structure and tougher nature of the metal compared with manganese steel weld metal.

The Mangcross electrode, therefore, can be used for welding cracks in manganese steel castings, such as broken rail tongues, gear wheels, etc., and for repairs to worn manganese steel crossings, dredger bucket lips,

crusher jaws, etc., and also for reinforcing mining and well-boring implements and parts of machinery.

The Mangcross weld metal has also a high resistance to corrosion and erosion, and is therefore very suitable for repairs to pelton wheel buckets, spear-heads, and other work of a similar kind.

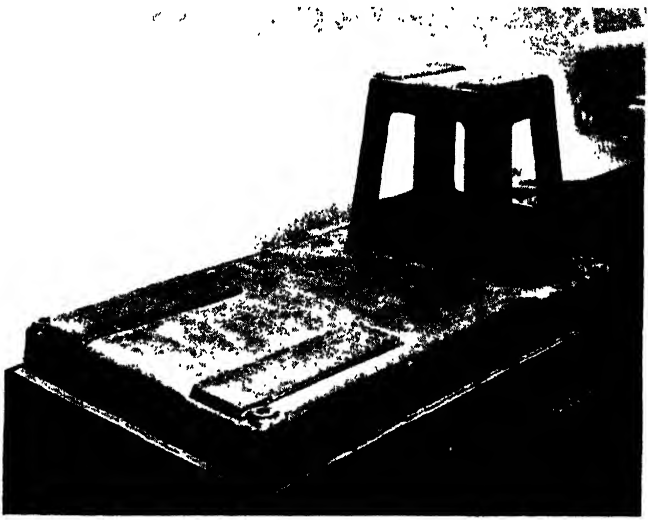


FIG. 521.—Welded Bedplate.

Welding in Machine Construction

The mild-steel fabricated bedplate shown in Fig. 521, at the instance of Messrs Thompson Bros., is typical of what can be done nowadays in mild steel in place of a casting. The work is cheaper, lighter, and stronger, even

though it may not have the direct appeal to the engineering mind that a good clean casting would; but it is obviously a practical proposition. There is a large amount of work of this kind now being done whereby light machine parts are built up from sheet metal and pressings and heavier ones from castings in iron or steel, or forgings or plates, and structural members, as the case may be. It is really impossible to visualise in a few pages the scope for the construction when dealt with by a skilful designer with practical experience in the art of welding.

In the case of baseplates for ships' capstan gears four of these are assembled together per ship, and this necessitates the side and ends of each being accurately machined so that when bolted all bearings are in line and centre to centre measurements are correct.

Each baseplate is built up of mild steel plate and, with the single exception of the round bosses about 2 in. thick, no rolled sections are used. Rolled sections were originally designed to suit riveted fabrication, and can in most cases be left out of a welded design of this type with a big saving in cost.

These baseplates measure approximately 7 ft. 9 in. by 4 ft. 6 in. by 1 ft. 3 in., and 5 ft. 6 in. by 4 ft. by 1 ft. 9 in., and consist of a $\frac{1}{2}$-in. baseplate, $\frac{1}{2}$-in. and $\frac{9}{16}$-in. top and bearing supporting plates, and $1\frac{3}{8}$-in. bearing plates. Side plates run completely round the outside of the holding-down bosses, $\frac{1}{2}$ and $\frac{1}{4}$ in. thick, and make an excellent trough for excess oil. The various parts are built up separately and then assembled on the $\frac{1}{2}$-in. baseplates, checked over for measurement and welded together.

In the early stages, $\frac{1}{8}$ in. was allowed for machining, but was found to be insufficient, cleaning up rather bare in places. Satisfactory results are, however, now obtained

by allowing $\frac{1}{4}$ in. extra thickness of plates for machining, save in one case. Here from end to end a considerable shrinkage has been found to occur, owing to numerous runs of welding across this particular part. The contraction, although little across one run of welding, has been found to amount to as much as $\frac{3}{16}$ in. across a baseplate about 4 ft. end to end. When one considers the amount of welding put into these baseplates, 150 lineal feet, this contraction can be easily understood and adequate provision allowed in order to bring about a satisfactory job.

A typical example of relatively heavy work is seen in railway carriage and wagon frames, and latterly in locomotive frames, the bogie shown in Fig. 522 showing a double frame welded bogie, a patent of Mr G. H. Sheffield. This design gives a structure of considerable transverse stability with a reduction of weight of 20 per cent. on cast steel. The vertical frame plates are suitably reinforced against shear by internal ribs welded into them before the upper and lower transverse cover plates are finally welded into the structure, thus providing a modified form of box girder. This enables the axle box springs to be located within the side frames, and the load upon the springs to be aligned through the centre line of the journals, thus producing a balanced structure under load. The openings surrounding the axle boxes are reinforced by internal stiffener plates, fillet and spot welded, to take shear due to load and reactions due to brake pressure. The fixed bolsters at each side of the swing bolsters are welded into the double side frames and further reinforced by deep gusset plates framing up the whole of the cross-angle stretchers, and thus triangulating the structure from side to side. The guide rubbing pieces on all the bolsters are welded into position. To the main bolster of the vehicle there are attached two circular

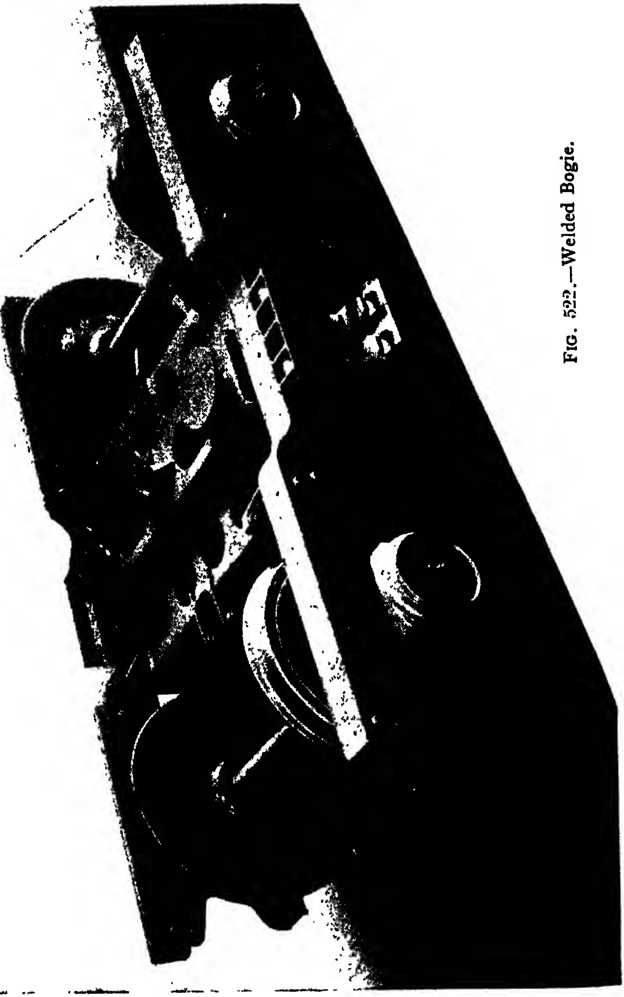


FIG. 522.—Welded Bogie.

plates superimposed upon the side bearers of the bogies. These bearers consist of circular shapes resting upon hemispherical centres and permitting transverse and longitudinal tilting of the bolster. No weight is carried upon the centre pin, which is free to adjust itself to angular movement in either direction. The purpose of the side bearer is to eliminate hunting and, incidentally, to reduce the bending moment on the main bolster by 40 per cent.

Structural Work

In this, as in shipbuilding, welding has been proved at least the equal in strength to good riveting, and with a considerable saving in labour. It is being extensively employed on steel buildings and bridge work by many engineers. By using welded construction, and by taking advantage of the continuity or fixity of the welded joint and of the other savings which the use of welding makes possible, the steel frame can now compete with the concrete building.

In view of the conditions which govern its use, the main effort is directed towards economy. On account of the high cost of steel it is important that the weight of steel used be reduced to a minimum, and it is always worth while to undertake somewhat elaborate computations to allow of this. For instance, if the shape of the building and arrangement of the steel work is such that continuity in the beams can be achieved, it is possible to make a saving of more than 20 per cent. in the weight of steel in the beams; a further substantial saving is made by eliminating the connection material, brackets, cleats, and so on, or at least by reducing it to a minimum, and in some cases an additional saving is effected by building stanchion shafts from flat plates in order to obtain a

section of large radius of gyration, which permits the allowable working stress to be increased. It is claimed that the overall saving in the weight of steel varies from 15 to 25 per cent. The cost per ton of steel has up to the present time been greater, but very little greater, than that of riveted steel, and the greater part of the reduction in weight is available as saving on the total cost of the frame.

Savings Effected

Use of Pressed Steel.—Successful carrying out of this class of work again devolves largely upon the designer, but the general procedure is for the whole of the steel to be cut to length at the mill and sent direct to the site by passing the fabricating shop entirely, and thus saving substantial cartage charges and shop overheads. In preparing the design an effort is made to obviate the use of cleats, gussets, or stiffeners of any sort for the beam to column connection, and the column splices and bases are made as simple as possible.

In erection, which is always a costly job on any riveted structure, the stanchions are placed in position, and are then held by timber shores until sufficient steel is erected to form a solid frame. The beams are lifted and clamped or held to the stanchion with lashing wires until they are welded. Though the method may appear at first sight to be crude, it is simple and effective, and much more rapid than might be expected. A gang consisting of an erector, a welder, and four labourers erect about 5 tons per shift, rising to 10 tons if conditions are specially favourable.

In Fig. 523 is shown a typical example of what can be done to cheapen and simplify a steel frame building by

the use of welded pressed steel sections. Adopted by a Paris firm of structural engineers, the members of the steel frame are made of plate 3 to 4 mm. thick, pressed to form rectangular hollow sections.

In order to give speed of erection the floors and walls are precast and erected in sections, and the hollow steel members are filled with concrete during the placing of the floor and wall slabs, and compacted by means of an electrical vibrating device.

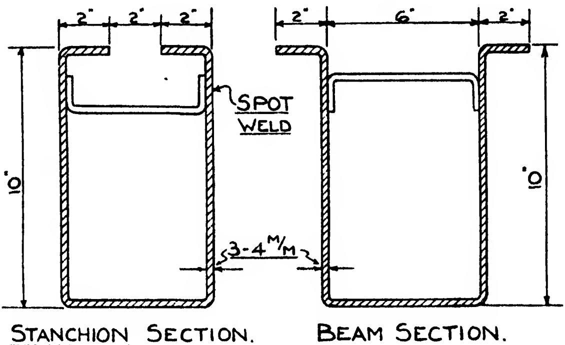


FIG. 523.—Welding on Structural Work.

The profile of the beam and stanchion sections are shown. The internal measurement of the beam section is equal to the external measurement of the stanchion section, so that when the bottom flange of the beam is cut away, it slips over the column section giving a simple and effective joint.

The structure is of one bay only, five storeys high. A complete bent is laid down and welded up on the ground and lifted into position as a unit. The longitudinal ties

are of trough section pressed from flat steel which carries a precast concrete plinth and supports the precast wall slabs. Since the steel work is quite smooth, and of simple rectangular contour, it is left exposed and merely finished by painting.

Bridge Strengthening

During the last thirty years railway engineers both in this country and abroad have been faced with the difficult problem of strengthening their steel bridges to carry the heavier locomotives now in use. This, in the main, involves the putting in of additional stiffening members without alteration to the structure as a whole or interference with traffic.

Welding is now almost universally employed in this class of work as the job largely involves the addition of web stiffeners to the lower flanges of the main and/or cross girders. Typical of this is the construction shown in Fig. 524. The stiffener is made of tee section, and is connected to the web by the outstanding leg, and to the flange plate by the platform, the outstanding leg being cut right away in a curved shape to avoid the flange. The tee is thus used in a very effective manner, and the weld on the flange is placed along the lines of stress. The welded steel bridge too is coming into vogue. Its advantages became apparent when the first all-welded highway bridge (Fig. 525) of considerable span in England was opened some years ago at Middlesbrough. This bridge is not only remarkable for its cantilever design but also for the application of the full web girder type, butt welding being carried out throughout instead of overlapped joints.

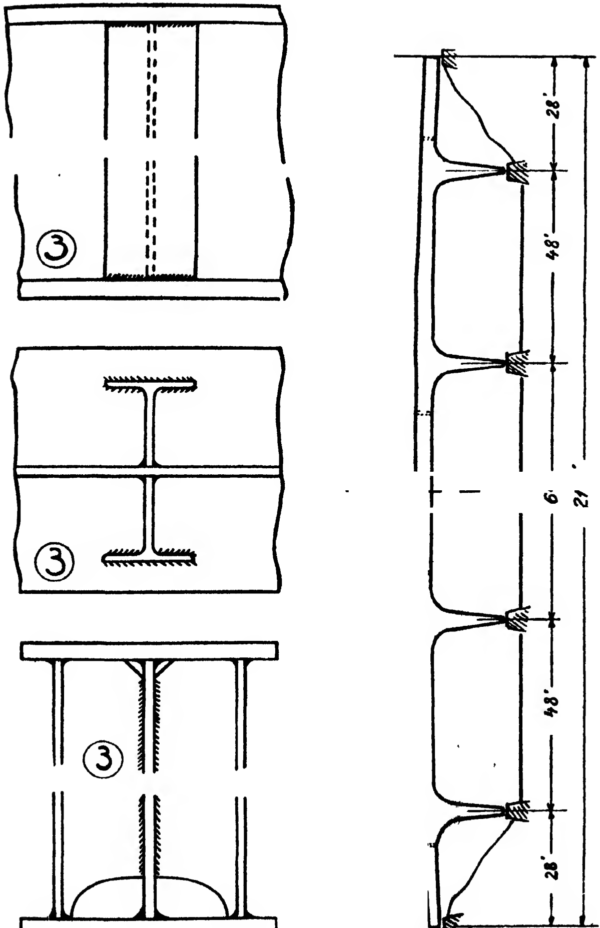


Fig. 524.—Welding in Bridge Work.

German engineers before the war evolved new types of plate girders for the class of structure as shown in Fig. 526. This depicts some of these types indicating the line of development. The form of rolled flanges, called "Wulstprofil," has been used for a number of plate girder bridges of considerable spans. Railway bridges of this type connect the Continent with the Isle of Rügen, and have plate girders of 52 m. span (172 ft.), the flange plates having a weight of about 9 tons each.

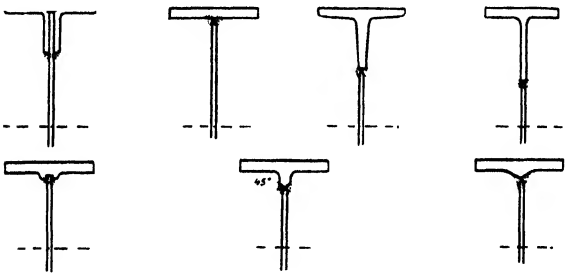


FIG. 526.—Welded Bridge Girders.

In constructing the bridge at Middlesbrough referred to, this, as will be seen from the diagram, is of the portal type and consists of five spans, varying in dimensions from 28 to 64 ft. It carries a roadway 38 ft. wide, and two footpaths each 9 ft. wide.

The loading allowed for on the roadway is a special load of a 100-ton lorry on four wheels plus 50 per cent. for impact—that is, 75 tons per axle—the remainder of the roadway being taken as carrying 150 lbs. per sq. ft. The girders under the carriageway are built up of webs, to which the top and bottom flanges are welded. Over

the two central supports and throughout the centre slung span the webs are $\frac{3}{4}$ in. thick; elsewhere the webs are $\frac{5}{8}$ in. thick. The top flanges are 12 in. wide, the bottom flanges are 13 in. wide, and the flange thicknesses vary from $\frac{7}{8}$ to 2 in. In all cases the flanges are in one thickness of plate. The welding of the flanges to the webs is in continuous seams, and at changes of flange plate the strength of the flanges is developed by butt welds. The stanchion legs are made up of a web $\frac{3}{4}$ in. thick for central stanchions and $\frac{5}{8}$ in. thick for the outer stanchions. To each web are welded plates 13 in. wide, forming a section similar to the girders above, and the girders and stanchions are made continuous by the interwelding of their webs and flanges.

The two longitudinal face girders supporting the footpaths and parapets, together with their supporting stanchion legs, are built up of sections similar to those under the carriageway. The scantlings are considerably lighter, and there are fewer changes of section.

Light Welding: Shop Production

Resistance Welding.—Under this heading comes those varieties of electric welding known as Butt Welding, Spot Welding, and Seam Welding. This class of work is carried out by placing in contact the parts which require welding and passing a very heavy current at low voltage through them. The electrical resistance at the point of contact has a high value compared with the rest of the circuit, and the temperature at the joint

consequently rises rapidly. When welding temperature is reached, mechanical pressure is applied to consolidate the metal and form a sound weld.

The low voltage employed at the weld is obtained by transforming down the current from alternating supply mains, where these are available.

The transformer is an integral part of the machine itself, and in most instances provision is made for regulation of the heating speed by plugging in to tappings on the primary side. A single-phase supply is essential, and may be obtained from a 3-phase supply, but in the case of the larger machines the Supply Authority may insist on the installation of a 3 to 1 phase transformer, or a motor generator.

Butt welding may be subdivided into slow butt welding and flash welding. In the slow weld the parts are brought into intimate contact and then the current is switched on. When welding temperature is reached the parts are forced together, causing an upset at the weld. This method is mostly used when welding solid uniform sections.

For thin sections flash welding is used. In this process the current is switched on and the parts brought together with only a slight pressure. Arcing takes place, and any unevenness at the ends burns away, while the whole area of the ends is rapidly raised to a high temperature. The application of a sudden heavy pressure forces out the burnt metal in the form of a thin fin, leaving only sound metal in the weld itself.

Spot welding is used for light work, as a general rule, as a substitute for riveting, to fasten two sheets of metal together by uniting them over an area equal to that of the rivet which would otherwise be used. In this case the current is applied by means of two tips or electrodes

between which two or more sheets are placed to be welded. These electrodes are brought together by means of a hand lever or pedal, or in certain cases by power-driven mechanism.

Mechanical pressure is applied to these electrodes through a spring, and when the spring is compressed to a certain degree, a switch is automatically closed. Current then flows until welding temperature is reached, when the spring is further compressed, consolidating the weld and cutting off the current.

In the majority of machines at present in use the operator has to judge the correct temperature, but this can now be done automatically by the use of automatic spot welders.

Spot welding is chiefly applied to the welding of steel from a few thousandths of an inch to half an inch thick, but brass, copper, and other non-ferrous metals of limited thickness may be welded satisfactorily.

Whilst spot welding makes a serviceable joint in the same way as a riveted one would, it is not intended to form either a gas-tight or liquid-tight joint. For the purpose it is usual to make use of seam welding, which is done by passing the sheets between two copper disc electrodes which form part of the electrical circuit. The sheets become heated to welding temperature in the path of the electrodes, and the pressure between these consolidates the weld.

Seam welding is used in the manufacture of oil and paint drums, refrigerators, electric ovens, etc., and the materials for which it is most suitable are mild steel and stainless steel. A maximum thickness of two $\frac{3}{16}$-in. steel sheets can be welded together.

As the disc electrodes are driven at a constant rate and a constant supply of current is passing, it is necessary

that the welding surfaces of the sheets should be clean. For this reason grinding, pickling, or sand-blasting is essential before seam welding black sheet.

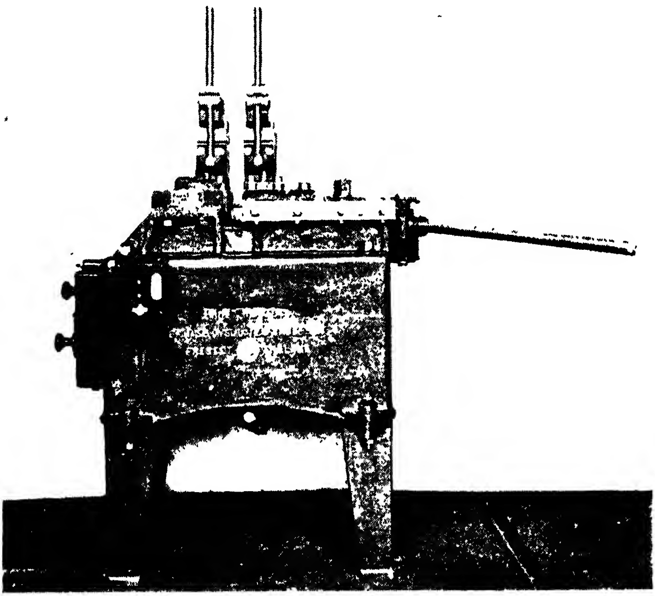


FIG 527.—Butt Welder.

Welding Machines

Butt Welding.—The machine shown in Fig. 527, as constructed by Messrs British Insulated Cables Ltd., is designed for butt welding clampable sections of both iron and mild steel up to 1 sq. in. area.

It consists of a cast-iron body upon which are mounted clamps suitable for the shape of the article it is desired to weld. One clamp is fixed and the other bolted to a saddle through which the upsetting pressure is applied by means of the hand lever shown.

The slide is made of cast iron, having a very large wearing surface, and thus the parts being welded are not likely to be out of alignment due to wear in the slide.

The transformer for reducing the normal alternate current supply to a low voltage and high current is mounted inside the base. The ends of the secondary are bolted directly to the clamp supports, and the current does not pass through the moving saddle, therefore the latter may be lubricated without any fear that the working of the machine will be affected.

The gap between the two clamps is adjusted by means of the largest hexagon nut on top of the slide. A stop is provided to allow the gap to be opened a definite amount when engaged on repetition work.

The plug box is situated on the left-hand side of the welder. Eight speeds are provided for, so that a suitable one may be found for any section within the range of the machine, " Fast 1 " being the quickest and " Slow 4 " the slowest.

The main switch consists of a contactor operated by means of the push-button control on the front of the machine. An automatic knock-off switch is provided, enabling the current to be cut off automatically when the weld is upset. The lower clamps, and in certain cases the electrode blocks, are water-cooled.

Automatic Machine for Flanging Tubes

The machine shown in Fig. 528 is one constructed by Messrs British Insulated Cables Ltd. for work of this

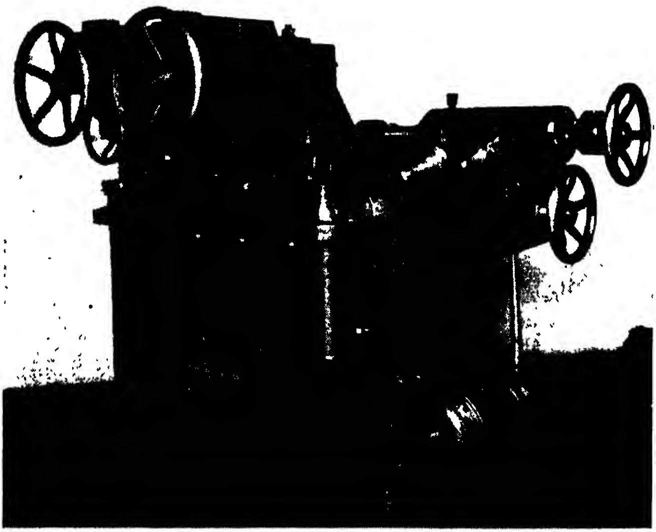


FIG. 528.—Automatic Welder.

class, and it is an automatic machine consisting of a standard transformer and clamping gear, but with special mechanism for welding.

The parts to be welded are fixed in the machine with suitable clamping gear, which may be either hand or

power operated. The welding operation is then entirely automatic.

There is a self-contained motor driving the upset gear. This is set in motion, the slide is slightly withdrawn, the current automatically switched on, and then the slide moves slowly forward. When the parts to be welded make contact the usual flashing takes place, and this is continued for a predetermined time, allowing the two ends to become incandescent ready for the final upsetting pressure. This is applied by means of a powerful spring, and its energy is released after the flashing has taken place. The work is then ready for removing from the machine. The operating switch is changed over, which causes the slide to be withdrawn to its original position. Two more pieces are then inserted in the machine and the switch once more changed over, and the same cycle of operations gone through.

Spot Welding.—In the production of light parts such as automobile components made from light pressings, stampings or strip, light machinery parts in general and a variety of metal utensils which come under the general heading of holloware, spot welding has facilitated the jointing of the parts to a remarkable degree. Ventilator shafts, ducts for fume extracting, etc., whether of black or galvanised sheet steel, may be conveniently built up by means of spot welding. In fact, there is hardly any sheet-metal work which cannot be welded with advantage

Another typical instance is seen in the production of

light dredger buckets. The older method necessitated punching holes, and the buckets had a comparatively short life owing to oxidation round the rivets. The spot welding method obviates this difficulty, makes a stronger bucket with a longer life for equal conditions of service and equal qualities and thickness of material.

Other useful applications of the system are making up guards for machinery, shovels and similar tools, and bearing in mind the main purpose of this operation—to eliminate light riveting—which is never really mechanically sound, it will be appreciated that the material is not weakened by punching or drilling, and the cost both of this operation and of the provision of rivets is saved.

A spot weld cannot work loose like a rivet, and the tightness of the junction between the metals is not affected by oxidation.

The cost of spot welding is approximately 10 per cent. of that of riveting, and spot welders can be operated quite satisfactorily by unskilled labour.

When good work of this kind is tested to destruction, the plates will invariably be torn in forcing the joint open, which amply demonstrates the strength of this simple form of weld. In Fig. 529 is shown a typical machine of this class. It is a sturdily built general purpose machine capable of handling a large range of work. The transformer is housed in a heavy cast-iron base, the trip switch and upsetting mechanism being totally enclosed. The pedal is of the swivel type so that it is possible to operate the machine from the side in

cases where the size of the article to be welded makes this necessary.

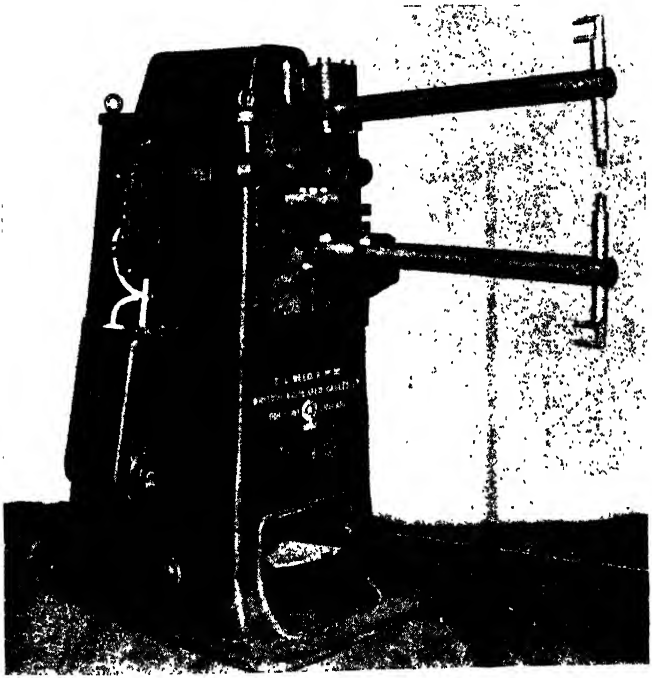


FIG. 529.—Spot Welder.

Other varieties of the same class of machine are constructed to deal with work as light as jewellery and dental plates, whilst others may be required to deal with steel plates up to $\frac{3}{4}$ in.

Welding material of the thicker gauges requires a heavy upsetting pressure to consolidate the weld, and in order to reduce fatigue to the operator a system of toggle levers is embodied in machines of this class.

For welding mild steel, it is usual for the machine to be fitted with an automatic relay whereby the weld is automatically made irrespective of the skill or judgment of the operator. On thick material the apparent heat on the surface is no indication of the internal condition, and the relay will not permit the weld to be consolidated until the internal condition of the material is suitable.

Butt Welding for Heavy Work

A fairly recent development in the important process of butt welding is the handling of heavy work by means of the automatic flash butt welder (Fig. 530). The vital matter here is to have the faces of both parts being welded a good fit over the whole section. Unless the condition is complied with, there is uneven distribution of the current over the cross-section of the weld, and therefore only some points of the cross-section are effectively welded. This is not so apparent in the welding of small parts, as the protruding points in this instance are generally very small, and shortly after the initiation of the weld they are forced away of their own accord due to the higher specific pressure per unit of area. Accordingly, the butt welding of objects with small cross-sections has always given good results. The abutting faces of large

objects, or those with complicated cross-sections, must, on the contrary, be carefully smoothed over and adapted to each other before any actual welding is done, and the

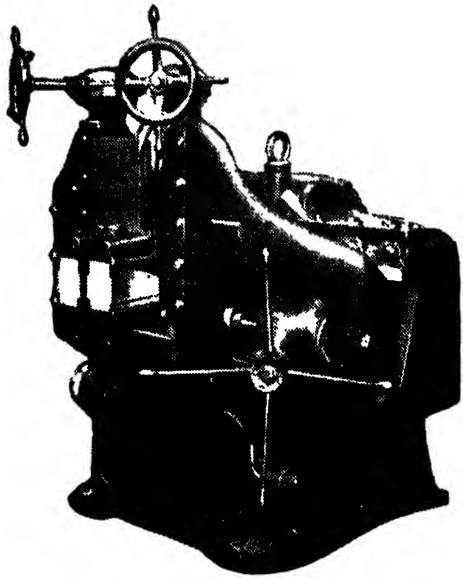


FIG. 530.—Flash Butt Welder.

production time required for this adds so much to the cost of the work as to render its economy doubtful.

With the modern system of flash butt welding, as introduced by the A.E.G. Co., who are responsible for the machine shown in Fig. 530, it is not necessary to prepare the faces of the materials to be welded together. The

quality of the weld is not impaired either by the roughness of the surfaces to be welded or by dirt. In point of fact, protruding parts are first flashed, so that the abutting surfaces are rendered smooth by the welding process itself. Simultaneously, all impurities are ejected during welding.

The flash welding method occasions a small beaded burr which can be very easily removed after the still red-hot weld is completed by means of a chisel. After the burr has been removed, the weld no longer exhibits any thickening; subsequent machining operations are therefore simple.

With the ordinary butt-welding process, on the contrary, a thick ridge always remains at the point of weld, which, with the exception of very small cross-sections, requires machining off by machine tools, such as planers, lathes, or milling machines.

The process is being extensively used in the welding of foundation rings for locomotive boilers, the welding of stems on to railway wagon buffers, the building up of crankshafts, the welding of forks to connecting rods, in the manufacture of steel railway sleepers, which are now so much in vogue, in ship construction and railway crossing work.

Soldering

Soldering may be roughly grouped under two headings :—

(*a*) Soft soldering using a lead tin or similar low melting metal mixture.

(*b*) Hard soldering using a harder metal which has a higher melting-point.

In the former grouping is the pewter and tinsmiths' solders having as a maximum a melting-point of, say, 350° C.

The latter grouping comprises roughly :—

(*a*) The copper phosphorus solder melting around 750° C.

(*b*) The silver solders which are alloys of copper, silver and zinc which melt around 850° C. as a maximum.

(*c*) The brass solders which are alloys of copper and zinc and melt around 950° C. maximum. As the alloy is a brass, the term brazing is often applied to the joining of articles with one of the brass solders.

(*d*) The copper solders have a very small alloy content and melt around 1,100° C. maximum.

The various compositions for both soft and hard solders have long been standardised and one should consult the relevant B.S.S. or that issued by any other national standard's authority.

The flux generally chosen for soft solders is a liquid and termed "spirits," whilst for the hard solders borax is chiefly used.

How the article and solder will be heated depends upon the equipment available, for one may use the blowpipe, a coal-gas torch, an oxygen-acetylene torch, an electric resistance, or pass the assembled articles through a furnace either gas or electrically heated.

Soldering and Welding

The two operations of soldering and welding are basically the same in that they are used to join metal parts together. As so often occurs in practice, the line of demarcation between the two processes tends to become blurred. However, for ease of definition one may suggest that: (*a*) soldering is when a non-ferrous joining medium is used, and (*b*) welding is when the joining medium has mainly a ferrous composition.

Weight per Foot of Round and Square Bar Iron

Inch.	Round.	Square.	Inch.	Round.	Square.
	·165	·211		42·464	54·084
	·373	·475		47·952	61·055
	·663	·845		53·760	68·448
	1·043	1·320		59·900	72·264
	1·493	1·901		66·350	84·480
	2·032	2·588		73·172	93·168
	2·654	3·380		80·304	102·24
	3·360	4·278		87·776	111·75
	4·147	5·280		90·525	121·66
	5·019	6·390		103·70	132·04
	5·972	7·604		112·16	142·81
	7·010	8·926		120·96	154·01
	8·128	10·352		130·04	165·63
	9·333	11·883		139·54	177·67
	10·616	13·520		149·32	190·13
	13·440	17·112		159·45	203·02
	16·588	21·120		169·85	216·33
	20·076	25·560		180·69	230·06
	23·888	30·416		191·80	244·22
	28·040	35·704		203·26	258·80
	32·512	41·408		215·04	273·79
	37·332	47·534		227·15	289·22

Weight of Flat Bar Iron per Lineal Foot

Width.	Thickness in Fractions of Inches.								
	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1
1	·84	1·05	1·26	1·48	1·69	2·11	2·53	2·95	3·38
$1\frac{1}{8}$	·95	1·18	1·42	1·66	1·90	2·37	2·85	3·32	3·80
$1\frac{1}{4}$	1·05	1·32	1·58	1·85	2·11	2·64	3·17	3·69	4·22
$1\frac{3}{8}$	1·16	1·45	1·74	2·03	2·32	2·90	3·48	4·06	4·64
$1\frac{1}{2}$	1·26	1·58	1·90	2·22	2·53	3·17	3·80	4·43	5·07
$1\frac{5}{8}$	1·37	1·71	2·06	2·40	2·74	3·43	4·12	4·80	5·49
$1\frac{3}{4}$	1·48	1·85	2·22	2·59	2·95	3·69	4·43	5·17	5·91
$1\frac{7}{8}$	1·58	1·98	2·37	2·77	3·17	3·96	4·75	5·54	6·33
2	1·69	2·11	2·53	2·96	3·38	4·22	5·07	5·91	6·76
$2\frac{1}{4}$	1·90	2·37	2·85	3·33	3·80	4·75	5·70	6·65	7·60
$2\frac{1}{2}$	2·11	2·64	3·17	3·69	4·22	5·28	6·33	7·39	8·45
$2\frac{3}{4}$	2·32	2·90	3·48	4·07	4·65	5·81	6·97	8·13	9·29
3	2·53	3·17	3·80	4·43	5·07	6·34	7·60	8·87	10·14
$3\frac{1}{4}$	2·74	3·43	4·12	4·80	5·49	6·86	8·24	9·61	10·98
$3\frac{1}{2}$	2·96	3·69	4·43	5·17	5·91	7·39	8·87	10·35	11·83
$3\frac{3}{4}$	3·17	3·96	4·75	5·54	6·33	7·92	9·50	11·09	12·67
4	3·38	4·22	5·07	5·91	6·76	8·45	10·14	11·83	13·52

Table of Conversion Factors

English to Metrical

Pounds per lineal foot	×	1·488	= kilos. per lineal metre
Pounds per lineal yard	×	0·496	= kilos. per lineal metre.
Tons per lineal foot	×	3333·33	= kilos. per lineal metre.
Tons per lineal yard	×	1111·11	= kilos. per lineal metre.
Pounds per mile	×	0·2818	= kilos. per lineal metre.
Pounds per square inch	×	0·0703	= kilos. per square centimetre
Tons per square inch	×	1·575	= kilos. per square millimetre
Pounds per square foot	×	4·883	= kilos. per square metre.
Tons per square foot	×	10·936	= tonnes per square metre.
Tons per square yard	×	1·215	= tonnes per square metre.
Pounds per cubic yard	×	0·5933	= kilos. per cubic metre.
Pounds per cubic foot	×	16·020	= kilos. per cubic metre.
Tons per cubic yard	×	1·329	= tonnes per cubic metre.
Grains per gallon	×	0·01426	= grammes per litre.
Pounds per gallon	×	0·09983	= kilos. per litre.
Gallons per square foot	×	48·905	= litres per square metre.
Foot-pounds	×	0·1382	= kilogrammetres.
Foot-tons	×	0·3333	= tonne-metres.
Horse power	×	1·0139	= force de cheval.
Pounds per H.P.	×	0·477	= kilos. per cheval.
Square feet per H.P.	×	0·0196	= square metre per cheval.
Cubic feet per H.P.	×	0·0279	= cubic metre per cheval.
Heat units	×	0·252	= calories.
Heat units per square foot	×	2·713	= calories per square metre.

Table of Conversion Factors—*contd.*

Metrical to English

Kilos. per lineal metre -	×	0·672	= pounds per lineal foot.
Kilos. per lineal metre -	×	2·016	= pounds per lineal yard.
Kilos. per lineal metre -	×	0·0003	= tons per lineal foot.
Kilos. per lineal metre -	×	0·0009	= tons per lineal yard.
Kilos. per lineal metre -	×	3·548	= pounds per mile.
Kilos. per square centimetre	×	14·223	= pounds per square inch
Kilos. per square millimetre	×	0·635	= tons per square inch.
Kilos. per square metre -	×	0·2048	= pounds per square foot.
Tonnes per square metre -	×	0·0914	= tons per square foot.
Tonnes per square metre -	×	0·823	= tons per square yard.
Kilos. per cubic metre -	×	1·686	= pounds per cubic yard.
Kilos. per cubic metre -	×	0·0624	= pounds per cubic foot.
Tonnes per cubic metre -	×	0·752	= tons per cubic yard.
Grammes per litre - -	×	73·09	= grains per gallon.
Kilos. per litre - -	×	10·438	= pounds per gallon.
Litres per square metre -	×	0·0204	= gallons per square foot.
Kilogrammetres - -	×	7·233	= foot-pounds.
Tonne-metres - -	×	3·000	= foot-tons.
Force de cheval - -	×	0·9863	= horse-power.
Kilos. per cheval - -	×	2·235	= pounds per H.P.
Square metre per cheval -	×	10·913	= square foot per H.P.
Cubic metre per cheval -	×	35·806	= cubic feet per H.P.
Calories - - -	×	3·986	= heat units.
Calories per square metre -	×	0·369	= heat units per square foot

Metric Weights and Measures

Approximate Equivalents

1 millimetre ($\frac{1}{1000}$ metre)	= ·03937 or $\frac{1}{25}$ inch.
1 centimetre ($\frac{1}{100}$ metre)	= ·3937 inch.
1 decimetre ($\frac{1}{10}$ metre)	= 3·937 inches.
1 metre	= 39·37 inches or $1\frac{1}{11}$ yards.
1 kilometre (1,000 metres)	= ·621 or $\frac{5}{8}$ English mile.
1 gramme	= 15·43 grains.
1 kilogramme	= 2·2046 lbs.
1 millier (metric ton)	= 1,000 kilos. (2,204·62 lbs.)
1 litre	= 1·761 (2·201 lbs.). 100 litres = 22 imp. gallons
1 inch	= 25·4 millimetres ($2\frac{1}{2}$ cm.).
1 foot	= ·3048 metre.
1 yard	= ·9144 metre.
1 mile	= 1·609 kilometres.
1 lb.	= ·4536 kilo.
1 cwt.	= 50·80 kilos.
1 ton	= 1016·40 kilos.
1 gallon	= 4·546 litres (10 lbs.).
1 square inch	= $6\frac{1}{2}$ square centimetres.
1 square centimetre	= ·155 square inch.
1 square yard	= $\frac{5}{6}$ square metre.
1 square metre	= $10\frac{3}{4}$ sq. ft. or $1\frac{1}{5}$ sq. yards.
1 cubic foot	= 28·3 litres (62·5 lbs.). (28·35 kilos.).
1 cubic yard	= $\frac{3}{4}$ cubic metre.
1 cubic metre	= $1\frac{1}{3}$ cubic yards.

To Convert

Lbs. into kilos	× ·453493.
Kilos. into lbs.	× 2·20462.
Lbs. per square inch	× ·0703 = kilos. per square cm.
Kilos. per square cm.	× 14·223 = lbs. per square inch
Inches into millimetres	× 25·39977.
Millimetres into inches	× ·03937043.
Square feet into square metres	× ·0929013.
Square metres into square feet	× 10·7641.
Gallons into litres	× 4·54102.
Litres into gallons	× ·220215.
English horse power into French force de cheval	× 1·01386.
French force de cheval into English horse power	× ·98633.

Table of Helix Angles

Giving the Setting Angles of Milling Machines, Twist Drill Flute Milling Machine Heads, etc.

Lead. / Diam.	Helix Angle.	Lead. / Diam.	Helix Angle.	Lead. / Diam.	Helix Angle.	Lead. / Diam.	Helix Angle.
2·00	57° 31′	5·20	31° 8′	8·75	19° 45′	20·00	8° 56′
2·20	55° 0′	5·40	30° 11′	9·00	19° 15′	25·00	7° 10′
2·40	52° 37′	5·60	29° 18′	9·50	18° 18′	30·00	5° 59′
2·60	50° 23′	5·80	28° 27′	10·00	17° 27′	35·00	5° 7′
2·80	48° 16′	6·00	27° 38′	10·50	16° 39′	40·00	4° 29′
3·00	46° 19′	6·20	26° 52′	11·00	15° 56′	50·00	3° 36′
3·20	44° 28′	6·40	26° 9′	11·50	15° 17′	60·00	3° 0′
3·40	42° 44′	6·60	25° 27′	12·00	14° 40′	70·00	2° 34′
3·60	41° 7′	6·80	24° 48′	12·50	14° 7′	80·00	2° 15′
3·80	39° 35′	7·00	24° 10′	13·00	13° 38′	90·00	2° 0′
4·00	38° 10′	7·25	23° 26′	14·00	12° 39′	100·00	1° 48′
4·20	36° 48′	7·50	22° 44′	15·00	11° 50′	120·00	1° 30′
4·40	35° 30′	7·75	22° 4′	16·00	11° 6′	140·00	1° 17′
4·60	34° 19′	8·00	21° 26′	17·00	10° 28′	160·00	1° 7′
4·80	33° 12′	8·25	20° 51′	18·00	9° 54′	180·00	1° 0′
5·00	32° 8′	8·50	20° 17′	19·00	9° 23′	200·00	0° 54′

Relative Weights of Metals to Wood Patterns

	Weight of Pattern in lbs. per Cubic Inch. No Cores.	Cast Iron. Cubic Inch = ·26 lb.	Cast Steel. Cubic Inch = ·28 lb.	Gun Metal. Cubic Inch = ·3 lb.	Aluminium. Cubic Inch = ·092 lb.
	Cubic Inch.	*Pro rata* or Relative Weights of Metals to Wood Patterns.			
Yellow pine	0·018	14·6	15·7	17	5·11
White pine	0·017	15·5	16·7	18	5·41
Baywood	0·020	13·2	14·2	15·2	4·6
Beech	0·025	10·5	11·3	12·2	3·68
Oak	0·031	8·5	9·1	9·8	2·97

Imperial, Birmingham, and American Wire Gauges

Imperial.			Birmingham.			American.		
No. of Gauge.	Equivalent Diam. in Inches.	Equivalent Diam. in Mm.	No. of Gauge.	Equivalent Diam. in Inches.	Equivalent Diam. in Mm.	No. of Gauge.	Equivalent Diam. in Inches.	Equivalent Diam. in Mm.
1	·300	7·620	1	·300	7·620	1	·289	7·340
2	·276	7·010	2	·284	7·213	2	·257	6·527
3	·252	6·400	3	·259	6·578	3	·229	5·816
4	·232	5·892	4	·238	6·045	4	·204	5·181
5	·212	5·384	5	·220	5·588	5	·182	4·622
6	·192	4·876	6	·203	5·156	6	·162	4·114
7	·176	4·470	7	·180	4·571	7	·144	3·657
8	·160	4·064	8	·165	4·191	8	·128	3·251
9	·144	3·657	9	·148	3·759	9	·114	2·895
10	·128	3·251	10	·134	3·403	10	·102	2·590
11	·116	2·946	11	·120	3·047	11	·090	2·286
12	·104	2·641	12	·109	2·768	12	·080	2·032
13	·092	2·336	13	·095	2·412	13	·072	1·828
14	·080	2·032	14	·083	2·108	14	·064	1·625
15	·072	1·828	15	·072	1·828	15	·057	1·447
16	·064	1·625	16	·065	1·650	16	·050	1·270
17	·056	1·421	17	·058	1·472	17	·045	1·142
18	·048	1·218	18	·049	1·244	18	·040	1·016
19	·040	1·016	19	·042	1·066	19	·036	·9140
20	·036	·9140	20	·035	·8886	20	·032	·8124
21	·032	·8124	21	·032	·8124	21	·0284	·7213
22	·028	·7109	22	·030	·7617	22	·0253	·6126
23	·024	·6093	23	·025	·6347	23	·022	·5585
24	·022	·5585	24	·022	·5585	24	·020	·5078
25	·020	·5078	25	·020	·5078	25	·018	·4570
26	·018	·4570	26	·018	·4570	26	·016	·4062
27	·016	·4062	27	.016	·4062	27	·014	·3555
28	·014	·3555	28	·014	·3555	28	·0122	·3100
29	·013	·3300	29	·013	·3300	29	·011	·2800
30	·012	·3046	30	·012	·3046	30	·010	·2539

Whitworth Gas and Water Pipe Threads

Pipes having an internal diameter of 1/8 in. have twenty-eight threads to the inch; an internal diameter of 1/4 in. and 3/8 in., nineteen threads to the inch; an internal diameter of 1/2 in., 5/8 in., 3/4 in., and 7/8 in., fourteen threads to the inch, and all others from 1 in. to 4 in. inclusive, eleven threads to the inch.

Internal Diam. of Pipe.	External Diam. of Pipe.	Diam. at Bottom of Thread.	Internal Diam. of Pipe.	External Diam. of Pipe.	Diam. at Bottom of Thread.	Internal Diam. of Pipe.	External Diam. of Pipe.	Diam. at Bottom of Thread.
1/8	·38	·34	1 3/8	1·74	1·63	2 1/2	3·0	2·88
1/4	·52	·45	1 1/2	1·88	1·76	2 5/8	3·12	3·01
3/8	·66	·59	1 5/8	2·02	1·90	2 3/4	3·25	3·13
1/2	·83	·73	1 3/4	2·16	2·04	2 7/8	3·37	3·25
5/8	·90	·81	1 7/8	2·24	2·13	3	3·48	3·37
3/4	1·04	·95	2	2·35	2·23	3 1/4	3·70	3·58
7/8	1·19	1·10	2 1/8	2·47	2·35	3 1/2	3·91	3·79
1	1·31	1·19	2 1/4	2·59	2·47	3 3/4	4·12	4·01
1 1/8	1·49	1·37	2 3/8	2·79	2·68	4	4·34	4·22
1 1/4	1·65	1·53						

Screw Threads and Thicknesses of Wrought-Iron Pipes

Briggs' American Standard

Diameter of Tube.			Thickness of Metal.	Screwed Ends.	
Nominal Inside.	Actual Inside.	Actual Outside.		Number of Threads per Inch.	Length of Perfect Screw.
Inch.	Inch.	Inch.	Inch.	No.	Inch.
1/8	0·270	0·405	0·068	27	0·19
1/4	0·364	0·540	0·088	18	0·29
3/8	0·494	0·675	0·091	18	0·30
1/2	0·623	0·840	0·109	14	0·39
3/4	0·824	1·050	0·113	14	0·40
1	1·048	1·315	0·134	11 1/2	0·51
1 1/4	1·380	1·660	0·140	11 1/2	0·54
1 1/2	1·610	1·900	0·145	11 1/2	0·55
2	2·067	2·375	0·154	11 1/2	0·58
2 1/2	2·408	2·875	0·204	8	0·89
3	3·067	3·500	0·217	8	0·95
3 1/2	3·548	4·000	0·226	8	1·00
4	4·026	4·500	0·237	8	1·05
4 1/2	4·508	5·000	0·246	8	1·10
5	5·045	5·563	0·259	8	1·16
6	6·065	6·625	0·280	8	1·26
7	7·023	7·625	0·301	8	1·36
8	8·000	8·625	0·322	8	1·46
9	9·000	9·688	0·344	8	1·57
10	10·019	10·750	0·366	8	1·68

Taper of conical ends 1 in 32 to axis of tube.

Decimal Equivalents of Millimetres and Millimetre Fractions

Mm.	Inch.	Mm.	Inch.	Mm.	Inch.
1/50 =	·00079	26/50 =	·02047	2 =	·07874
2/50 =	·00157	27/50 =	·02126	3 =	·11811
3/50 =	·00236	28/50 =	·02205	4 =	·15748
4/50 =	·00315	29/50 =	·02283	5 =	·19685
5/50 =	·00394	30/50 =	·02362	6 =	·23622
6/50 =	·00472	31/50 =	·02441	7 =	·27559
7/50 =	·00551	32/50 =	·02520	8 =	·31496
8/50 =	·00630	33/50 =	·02598	9 =	·35433
9/50 =	·00709	34/50 =	·02677	10 =	·39370
10/50 =	·00787	35/50 =	·02756	11 =	·43307
11/50 =	·00866	36/50 =	·02835	12 =	·47244
12/50 =	·00945	37/50 =	·02913	13 =	·51181
13/50 =	·01024	38/50 =	·02992	14 =	·55118
14/50 =	·01102	39/50 =	·03071	15 =	·59055
15/50 =	·01181	40/50 =	·03150	16 =	·62992
16/50 =	·01260	41/50 =	·03228	17 =	·66929
17/50 =	·01339	42/50 =	·03307	18 =	·70866
18/50 =	·01417	43/50 =	·03386	19 =	·74803
19/50 =	·01496	44/50 =	·03465	20 =	·78740
20/50 =	·01575	45/50 =	·03543	21 =	·82677
21/50 =	·01654	46/50 =	·03622	22 =	·86614
22/50 =	·01732	47/50 =	·03701	23 =	·90551
23/50 =	·01811	48/50 =	·03780	24 =	·94488
24/50 =	·01890	49/50 =	·03858	25 =	·98425
25/50 =	·01969	1 =	·03937	26 =	1·02362

10 mm. = 1 centimetre = 0·3937 inch.
10 cm. = 1 decimetre = 3·937 inches.
10 dm. = 1 metre = 39·37 inches.
25·4 mm. = 1 English inch.

Tapers per Foot at Corresponding Angles

Taper per Foot.	Included Angle.	Angle with Centre Line.	Taper per Foot.	Included Angle.	Angle with Centre Line.
1/8	0° 36′	0° 18′	1	4° 46′	2° 23′
1/4	1° 12′	0° 36′	1 1/2	7° 09′	3° 35′
5/16	1° 30′	0° 45′	1 3/4	8° 20′	4° 10′
3/8	1° 47′	0° 54′	2	9° 31′	4° 46′
7/16	2° 05′	1° 02′	2 1/2	11° 54′	5° 57′
1/2	2° 23′	1° 12′	3	14° 15′	7° 08′
3/4	3° 35′	1° 47′	3 1/2	16° 36′	8° 18′
15/16	4° 28′	2° 14′	4	18° 55′	9° 28

Wire Gauge

Sizes in Decimal Parts of an Inch

No. of Wire Gauge.	American or Brown & Sharpe.	Birmingham or Stubs' Wire.	Stubs' Steel Wire.	U.S. Standard for Plate.	No. of Wire Gauge.
000000	...	...	...	·46875	000000
00000	...	...	...	·4375	00000
0000	·46	·454	...	·40625	0000
000	·40964	·425	...	·375	000
00	·3648	·38	...	·34375	00
0	·32486	·34	...	·3125	0
1	·2893	·3	·227	·28125	1
2	·25763	·284	·219	·265625	2
3	·22942	·259	·212	·25	3
4	·20431	·238	·207	·234375	4
5	·18194	·22	·204	·21875	5
6	·16202	·203	·201	·203125	6
7	·14428	·18	·199	·1875	7
8	·12849	·165	·197	·171875	8
9	·11443	·148	·194	·15625	9
10	·10189	·134	·191	·140625	10
11	·090742	·12	·188	·125	11
12	·080808	·109	·185	·109375	12
13	·071961	·095	·182	·09375	13
14	·064084	·083	·180	·078125	14
15	·057068	·072	·178	·0703125	15
16	·05082	·065	·175	·0625	16
17	·045257	·058	·172	·05625	17
18	·040303	·049	·168	·05	18
19	·03589	·042	·164	·04375	19
20	·031961	·035	·161	·0375	20
21	·028462	·032	·157	·034375	21
22	·025347	·028	·155	·03125	22
23	·022571	·025	·153	·028125	23
24	·0201	·022	·151	·025	24
25	·0179	·02	·148	·021875	25
26	·01594	·018	·146	·01875	26
27	·014195	·016	·143	·0171875	27
28	·012641	·014	·139	·015625	28
29	·011257	·013	·134	·0140625	29
30	·010025	·012	·127	·0125	30
31	·008928	·01	·120	·0109375	31
32	·00795	·009	·115	·01015625	32
33	·00708	·008	·112	·009375	33
34	·006304	·007	·110	·00859375	34
35	·005614	·005	·108	·0078125	35
36	·005	·004	·106	·00703125	36
37	·004453	...	·103	·006640625	37
38	·003965	...	·101	·00625	38
39	·003531	...	·099	...	39
40	·003144	...	·097	...	40

METRIC OR FRENCH MEASURES

Measures of Capacity

1 Litre (l.) = 1 cub. decimetre = 61·0270515 cub. in., or 0·03531 cub. ft., or 1·0567 liquid qt., or 0·908 dry qt., or 0·26427 Amer. gal.

10 Litres = 1 decalitre (dl.) - - - = 2·6417 gal., or 1·135 pk.

10 Decalitres = 1 hectolitre (hl.) - - = 2·8375 bu.

10 Hectolitres = 1 kilolitre (kl.) - - = 61027·0515 cub. in. or 28·375 bu.

1 cub. ft. = 28·317 l., 1 gallon, Amer. = 3·785 l., 1 gallon, Brit. = 4·543 l.

Measures of Length

1 Millimetre (mm.) - - - - - = 0·03937079 inch, or about $\frac{1}{25}$ inch.

10 Millimetres = 1 centimetre (cm.) - - = 0·3937079 inch.

10 Centimetres = 1 decimetre (dm.) - - = 3·937079 ,,

10 Decimetres = 1 metre (m.) = 39·37079 inches, 3·2808992 feet, or 1·09361 yards.

10 Metres = 1 decametre (dm.) - - - = 32·808992 feet.

10 Decametres = 1 hectometre (hm.) - - = 19·927817 rods.

10 Hectometres = 1 kilometre (km.) - - = 1093·61 yards, or 0·6213824 mile.

10 Kilometres = 1 myriametre (mm.) - - = 6·213824 miles.

1 inch = 2·54 cm., 1 foot = 0·3048 m., 1 yard = 0·9144 m., 1 rod = 0·5029 dm., 1 mile = 1·6093 km.

Measures of Weight

1 Gramme (g.) = 15·4324874 gr. Troy, or 0·03215 oz., or 0·03527398 oz. avoir.

10 Grammes = 1 decagramme (dg.) Troy - = 0·3527398 oz. avoir.

10 Decagrammes = 1 hectogramme (hg.) - = 3·527398 ,,

10 Hectogrammes = 1 kilogramme (kg.) - = 2·20462125 lbs.

1,000 Kilogrammes = 1 tonne (t.) = 2204·62125 lbs., or 1·1023 tons of 2,000 lbs., or 0·9842 tons of 2,240 lbs., or 19·68 cwt.

1 grain = 0·0648 gr., 1 oz. avoir. = 23·35 gr., 1 lb. = 0·4536 kg., 1 ton. 2,000 lbs. = 0·9072 t., 1 ton, 2,240 lbs. = 1·016 t., or 1,016 kg.

Weights of Round and Square Bars of Steel in Pounds per Lineal Foot

Diameter in Inches.	Weight of Round Bar One Foot Long.	Weight of Square Bar One Foot Long.	Diameter in Inches.	Weight of Round Bar One Foot Long.	Weight of Square Bar One Foot Long.
0	...	...	2	10·679	13·596
1/16	·010	·013	1/16	11·362	14·463
1/8	·041	·053	1/8	12·056	15·351
3/16	·093	·119	3/16	12 780	16·269
1/4	·167	·212	1/4	13·515	17·217
5/16	·261	·332	5/16	14·280	18·186
3/8	·375	·478	3/8	15·065	19·176
7/16	·511	·650	7/16	15·861	20·196
1/2	·667	·849	1/2	16·687	21·246
9/16	·844	1·076	9/16	17·533	22·327
5/8	1·043	1·328	5/8	18·400	23·429
11/16	1·261	1·607	11/16	19·288	24·561
3/4	1·502	1·912	3/4	20·196	25·714
13/16	1·762	2·245	13/16	21·124	26·897
7/8	2·044	2·603	7/8	22·072	28·101
15/16	2·347	2·988	15/16	23·041	29·335
1	2·670	3·399	3	24·031	30·600
1/16	3·014	3·838	1/16	25·041	31·885
1/8	3·379	4·303	1/8	26·081	33·201
3/16	3·765	4·795	3/16	27·132	34·547
1/4	4·172	5·312	1/4	28·203	35·914
5/16	4·600	5·856	5/16	29·304	37·311
3/8	5·049	6·428	3/8	30·416	38·729
7/16	5·518	7·025	7/16	31·558	40·177
1/2	6·007	7·650	1/2	32·711	41·646
9/16	6·519	8·300	9/16	33·894	43·146
5/8	7·051	8·978	5/8	35·088	44·676
11/16	7·604	9·681	11/16	36·312	46·236
3/4	8·178	10·414	3/4	37·556	47·817
13/16	8·772	11·169	13/16	38·811	49·419
7/8	9·388	11·954	7/8	40·096	51·051
15/16	10·024	12·760	15/16	41·401	52·713

Table of Decimal Equivalents of 8ths, 16ths, 32ds, and 64ths of an Inch

8ths

$\frac{1}{8}$ = ·125
$\frac{1}{4}$ = ·250
$\frac{3}{8}$ = ·375
$\frac{1}{2}$ = ·500
$\frac{5}{8}$ = ·625
$\frac{3}{4}$ = ·750
$\frac{7}{8}$ = ·875

16ths

$\frac{1}{16}$ = ·0625
$\frac{3}{16}$ = ·1875
$\frac{5}{16}$ = ·3125
$\frac{7}{16}$ = ·4375
$\frac{9}{16}$ = ·5625
$\frac{11}{16}$ = ·6875
$\frac{13}{16}$ = ·8125
$\frac{15}{16}$ = ·9375

32ds

$\frac{1}{32}$ = 03125
$\frac{3}{32}$ = ·09375
$\frac{5}{32}$ = ·15625
$\frac{7}{32}$ = ·21875
$\frac{9}{32}$ = ·28125
$\frac{11}{32}$ = ·34375
$\frac{13}{32}$ = ·40625
$\frac{15}{32}$ = ·46875
$\frac{17}{32}$ = ·53125
$\frac{19}{32}$ = ·59375
$\frac{21}{32}$ = ·65625
$\frac{23}{32}$ = ·71875
$\frac{25}{32}$ = ·78125
$\frac{27}{32}$ = ·84375
$\frac{29}{32}$ = ·90625
$\frac{31}{32}$ = ·96875

64ths

$\frac{1}{64}$ = ·015625
$\frac{3}{64}$ = ·046875
$\frac{5}{64}$ = ·078125
$\frac{7}{64}$ = ·109375
$\frac{9}{64}$ = ·140625
$\frac{11}{64}$ = ·171875
$\frac{13}{64}$ = ·203125
$\frac{15}{64}$ = ·234375
$\frac{17}{64}$ = ·265625
$\frac{19}{64}$ = 296875
$\frac{21}{64}$ = ·328125
$\frac{23}{64}$ = ·359375
$\frac{25}{64}$ = ·390625
$\frac{27}{64}$ = ·421875
$\frac{29}{64}$ = ·453125
$\frac{31}{64}$ = ·484375
$\frac{33}{64}$ = ·515625
$\frac{35}{64}$ = ·546875
$\frac{37}{64}$ = ·578125
$\frac{39}{64}$ = ·609375
$\frac{41}{64}$ = ·640625
$\frac{43}{64}$ = ·671875
$\frac{45}{64}$ = ·703125
$\frac{47}{64}$ = ·734375
$\frac{49}{64}$ = ·765625
$\frac{51}{64}$ = ·796875
$\frac{53}{64}$ = ·828125
$\frac{55}{64}$ = ·859375
$\frac{57}{64}$ = ·890625
$\frac{59}{64}$ = ·921875
$\frac{61}{64}$ = ·953125
$\frac{63}{64}$ = ·984375

Rules Relative to the Circle, etc.

To Find Circumference—

Multiply diameter by 3·1416.
Or divide ,, ,, 0·3183.

To Find Diameter—

Multiply circumference by 0·3183.
Or divide ,, ,, 3·1416.

To Find Radius—

Multiply circumference by 0·15915.
Or divide ,, ,, 6·28318.

To Find Side of an Inscribed Square—

Multiply diameter by 0·7071.
Or multiply circumference by 0·2251.
,, divide ,, ,, 4·4428.

To Find Side of an Equal Square—

Multiply diameter by 0·8862.
Or divide ,, ,, 1·1284.
,, multiply circumference by 0·2821.
,, divide ,, ,, 3·545.

SQUARE—

A side multiplied by 1·4142 equals diameter of its circumscribing circle.

A side multiplied by 4·443 equals circumference of its circumscribing circle.

A side multiplied by 1·128 equals diameter of an equal circle.
,, ,, 3·547 ,, circumference of an equal circle.

Square inches multiplied by 1·273 equal circle inches of an equal circle.

To Find the Area of a Circle—

Multiply circumference by one quarter of the diameter.
Or ,, the square of diameter by 0·7854.
,, ,, circumference ,, ·07958.
,, ,, ½ diameter ,, 3·1416.

To Find the Surface of a Sphere or Globe—

Multiply the diameter by the circumference.
Or ,, square of diameter by 3·1416.
,, four times the square of radius ,, 3·1416.

To Find the Weight of Brass and Copper Sheets, Rods, and Bars—

Ascertain the number of cubic inches in piece and multiply same by weight per cubic inch.
Brass, 0·2972.
Copper, 0·3212.
Or multiply the length by the breadth (in feet) and product by weight in pounds per square foot.

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